ENHANCED CONCEPTUAL SITE MODEL FOR THE LOWER BASIN COEUR D'ALENE RIVER

Updated Synopsis for the Lower Basin of the Coeur d'Alene River

Bunker Hill Mining and Metallurgical Complex Superfund Site

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1.0 Relevant History and Background

1.1 Introduction

This technical memorandum provides an updated synthesis of the enhanced conceptual site model (ECSM)[1] for the Lower Basin of the Coeur d'Alene River, which is part of the Bunker Hill Mining and Metallurgical Complex Superfund Site. Historical mine waste disposal and flood events in the Coeur d'Alene River Basin have resulted in fluvial transport and deposition of sediment contaminated with heavy metals, including lead and zinc, in approximately 20 square miles of the riverbed, lakes, marshes, wetlands and agricultural lands of the Lower Basin. The Lower Basin, from the confluence of the North and South Forks to Coeur d'Alene Lake, includes the approximately 37-mile mainstem channel and associated floodplain, wetlands, and lateral lakes in the Coeur d'Alene River valley (Exhibit 1).

There are two distinct geomorphic reaches within the Lower Basin: a braided reach and a meandering reach (Bookstrom et al., 1999; Box et al., 2005). The breakpoint defining these reaches is located about river mile (RM) 160, near Mission Flats, where the river slope transitions from a higher gradient (0.0007 foot per foot [ft/ft] to a low-gradient (0.0001 ft/ft) system. Water levels in the low-gradient meandering reach are strongly influenced by fluctuations of the level of Coeur d'Alene Lake and the seasonal operation of Post Falls Dam.

The lower, meandering reach extends from RM 160 downstream to the river's mouth at Coeur d'Alene Lake near the town of Harrison (RM 131). This 29-mile reach is characterized by a single channel that winds through a broad, flat floodplain. The channel bed material is dominated by sand-size particles. In this reach, **the floodplain is tightly linked to the river, resulting in significant interaction of water and sediment between the main channel and floodplain, wetlands, and lateral lakes, further influenced by a series of levees and embankments**.

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[1] The ECSM is a compilation of nine technical memorandums that reflect data, analyses, and studies available through 2010 of contaminant nature and extent, and fate and transport. The ECSM included a listing of data gaps and data needs, which guided data collection and evaluation since 2010. These more recent studies, completed between 2010 and 2019, were summarized in a series of technical memorandum addendums, linked to the original ECSM memorandums. This synopsis is based on the findings of the ECSM and subsequent key addendums, which are available at: https://cumulis.epa.gov/supercpad/SiteProfiles/index.cfm?fuseaction=second.scs&id=1000195&doc=Y&colid=35748&region=10&type=SC.

1.2 Mining History

The pattern of lead concentrations in riverbed sediments is interpreted to reflect the relative age of the deposits, which in turn reflects, in part, changes in ore-processing practices over time. The historical floodplain contamination era, when the majority of tailings were released to the river, was 1903 to 1968 (Bookstrom et al., 2004). The deepest (and, therefore, earliest) mining deposits contain the highest concentrations of lead in part because of the relatively low efficiency of the jig process of milling in extracting lead from the ore. Later mining practices such as flotation processing resulted in higher rates of lead recovery and lower lead concentrations in tailings. The physical characteristics of mine waste also changed as more efficient ore processing produced more finely-ground material and "slimes". Mine waste was also released episodically as sediment retention "plank dams" failed, sending sediment pulses downstream.

More recent deposits (after about 1968, when direct discharge of milling waste to the South Fork ceased), reflect a mixture of remobilized contaminated sediment and cleaner sediments. These newer deposits have lower lead concentrations relative to those from the era of direct disposal. Lead in floodplain sediments was estimated to have increased from 17 tons per decade prior to 1886 (background rate), to 18,000 tons per decade from 1903 to 1980 (historical contamination relative to the Mount Saint Helens ash layer), and then decreased to 6,000 tons per decade from 1980 to 1993, (Bookstrom et al., 2004).

The result of this mixed history of mine processing and waste disposal was the heterogeneous deposition of mine waste-contaminated sediments of variable thickness, concentrations, and grain sizes in the riverbed, floodplain, wetlands, and lateral lakes. The mass of contaminated sediments stored in the riverbed is estimated at approximately 5 to 11 million metric tons (CH2M, 2017a).

1.3 2002 Interim Record of Decision Elements

The 2002 interim Record of Decision (ROD) cites specific alternatives to be considered as remedial actions:

- Channel dredging: Implement periodic removal of river bed sediments in Dudley Reach or other natural depositional areas
- Wetland remediation: Reduce exposure using a combination of removals, capping, and soil amendments in areas of high waterfowl use, high lead, and relatively low recontamination potential
- Splay areas: Construct and operate sediment traps at four splay areas where the river overflows its banks during high flow conditions after implementing a pilot project at one area
- Bank stabilization: Stabilize banks and revegetate removal areas to protect riparian zone ecological receptors and humans.
- Other viable alternatives to reduce particulate lead transport

The desired net effect of any combination of remedial actions is to demonstrate progress, through monitoring, toward meeting the following ROD benchmarks:

- Reduce particulate lead loading in the river
- Reduce soil toxicity for songbirds, small mammals, and riparian plants
- Reduce human exposure
- Reduce sediment toxicity and waterfowl mortality in wetlands
- Reduce sediment toxicity to ducks and fishes in Coeur d'Alene Lake
- Reduce riparian soil toxicity for riparian receptors

2.0 External Drivers of River Behavior

2.1 Basin Hydrology

The Lower Basin has unregulated flow from its two primary tributaries, with a majority of flow coming from the North Fork of the Coeur d'Alene River and the remainder of the flow coming from the South Fork. **The North Fork contributes approximately four times as much flow to the mainstem as the South Fork.** Tributaries (primarily intermittent streams) in the 37 miles between the North and South Fork confluence and the mouth of the Coeur d'Alene River at Harrison contribute approximately 11 percent of total water volume on average.

The hydrologic drivers of flood events in the Lower Basin are generally "flashy" (characterized by rapid changes in flow from storm-driven rain or rain-on-snow) events in winter, and more gradual snowmelt-based events in the spring. In the winter, heavy rains and rapid snowmelt increase runoff abruptly from low winter base flows to short-duration peak flows, such as occurred during the winters of 1995, 1996, and 1997 (Box et al., 2005). In contrast, during the spring, more gradual melting of snow in the basin creates slower, but longer duration, changes in discharge.

Flow at the Cataldo gaging station (RM 163) is typically used to define flow magnitude in the Lower Basin (e.g., overbank flow generally occurs when discharge at the Cataldo gaging station exceeds about 20,000 cubic feet per second [cfs]). Flows greater than 20,000 cfs typically overtop levees and produce overbank flow, with the location and timing of overtopping depending on the rate of increases in flow and existing water levels. Lateral connecting channels ("tie channels") act as conduits to and from lateral lakes and wetlands at flows less than 20,000 cfs. **The distribution and deposition of contaminated sediments in the Lower Basin are closely tied to overbank flow dynamics**. The Lower Basin generally experiences higher rates of overbank exchange as flow and water surface elevations (WSEs) increase. Spring events tend to flow overbank at lower flows, and for longer durations, because of the higher average system WSE caused by the backwater effect (Exhibit 2) generated by Coeur d'Alene Lake.

The Lower Basin is characterized by numerous, large off-channel lakes, marshes, and floodplain areas. Flow attenuation is created when water is routed into these off-channel areas, reducing in-channel flow by temporarily storing water in the floodplain, and reducing the magnitude of peak flow at Harrison, compared to peak flow at Cataldo. **Flow attenuation is generally higher for winter events and lower for spring events because winter events are generally flashier**, with smaller overall event volumes and steeper rising limbs, and because floodplain storage capacity is higher at the low water levels typical of winter conditions.

The concept of variable flow attenuation is important in understanding the impacts of specific events on the system. The magnitude and timing of river flow may be attenuated by several factors at once (e.g., flood event type, available floodplain storage, event duration), and therefore different flood characteristics and outcomes commonly result from inflows of similar magnitudes. As a result, **the downstream impact of two floods with identical peak discharge at the Cataldo gaging station may be quite different, depending on flow attenuation**.

2.2 Coeur d'Alene Lake Level

The Coeur d'Alene Lake level was affected by the construction of Post Falls Dam around 1907, which raised the lake level 6.0 feet (from 2121 to 2127 feet). Additional improvements to the dam in 1942 raised the lake level another 1.5 feet to the current normal summer operating pool elevation of 2128.5 (Black, 2003; Parametrix, 2003). During most of the summer (late May to September), flow velocity through the Lower Basin is low because the lake summer operating pool elevation is about the same as the river water surface elevation at the Old Mission boat launch (2128.5 feet) at RM 160, nearly 30 miles upstream. Consequently**, there is little velocity in the river channel and almost no**

downstream transport of sediments below RM 160 during the summer because of the backwater effect (Bookstrom et al., 1999).

Downstream from RM 160, flow exchange with the floodplain during flood conditions is closely tied to the backwater effect. This is especially true lower in the system, where the backwater effect makes a larger difference. Higher in the system, such as near the Cataldo gage (RM 163), there is relatively little impact of backwater effect on floodplain exchange.

For example, at the lake level recorded during the January 2011 flood event, there was no floodwater exchange into Strobl Field (RM 149). However, if the lake level (i.e., downstream water surface boundary) is modeled in the sediment transport model (STM) as similar to water surface elevation recorded at the time of the May 2008 flood event—about 4 feet higher—flow and contaminated sediment from the river would enter this portion of the floodplain. Although floodwater exchanges were significantly different between the January 2011 and May 2008 events, peak flow rates were about the same during both floods.

At the Killarney tie channel, backwater influence can be complex because of interactions between inflow *and* outflow pathways. The backwater influence, which may increase from prolonged or repeated flooding, can fill lateral lakes and create a partial hydraulic blocking effect, thereby reducing additional inflow, as observed in recent flooding and in modeling results. The magnitude and season of referenced floods are provided in Exhibit 3 for further context.

This "lake level effect" or "backwater effect" influences factors such as flow attenuation, shear stress, peak flow travel times, water surface elevations, and channel flow rates in different parts of the Lower Basin, as well as patterns of floodplain flow and sediment deposition. For this reason, peak WSE rates do not always coincide with peak discharge rates and **peak flow alone is not a reliable indicator of contaminant movement.** Antecedent lake levels, rates of rise in flood flows ("flashiness"), periods of time between floods, and flood duration are all variables with potentially significant effects on lead mobilization and transport.

2.3 Mine Waste Supply, Sedimentation and Cessation

2.3.1 Riverbed Response

The disposal of mine waste to the river system over many decades triggered multiple geomorphic responses. The response of the river system to chronic and acute sediment pulses of different magnitudes and grain sizes has been a series of aggradational and degradational signals over time. This section describes how the riverbed responded to these disturbances, how this response has changed over time, and implications for remedial design.

Riverbed aggradation occurred in the Lower Basin during times of heavy loading of mine tailings into the streams in the Upper Basin. This trend is most apparent in data from the 1930s through 1950s, from dredging-related reports in the Springston and Killarney reaches. Although increased sediment supply was the apparent primary cause for aggradation of the Coeur d'Alene River**, the construction and raising of Post Falls Dam may have accelerated aggradation processes.**

Riverbed degradation appears to have occurred over the past five decades, following the cessation of direct mine waste discharge into the South Fork. Multiple sets of bathymetric data and surveyed cross-sections (Exhibit 4) show that this trend is strongest and most consistent in the Killarney Reach (RM 143 to RM 151), but is also apparent in downstream (Springston) and upstream (Dudley) reaches. **Net mass change is most apparent in dune and plane bed geomorphic environments. These geomorphic bedforms are found on the riverbed more than other bedforms** (CH2M, 2016).

The Killarney reach shows the highest erosion rate among the reaches, with about 4 centimeters per year (cm/year) of erosion. There is less agreement in absolute erosion magnitude in the Springston and

Dudley reaches; however, estimated values are between 0 and 4 cm/year of erosion in these reaches (Exhibit 5). Reach-averaged bed erosion rates vary from 37 to 109 cm of erosion over 49 years (0.8 to 2.2 cm/year), and average 67 cm of erosion (1.4 cm/year) over the entire river. However, **single erosion rate values for the entire river do not reflect the trends that appear to differ substantially in different reaches of the river; smaller scale dynamics can vary from erosional to depositional.**

Additionally, **erosion patterns are generally episodic (event-based) and riverbed change is not generally a gradual process.** The STM corroborates the observed data, showing that most reaches exhibit net overall erosion, with portions of the downstream-most reaches showing deposition, over a 30-year simulation. Downstream-most reaches are most prone to low shear stress caused by the backwater effect, and subsequent deposition.

Evidence for net bed erosion can be seen in a comparison of suspended sediment concentration rating curves at the Cataldo and Harrison gaging stations. Contemporaneous measurements of suspended sediment concentration and discharge have been collected at U.S. Geological Survey (USGS) gaging stations to construct suspended sediment concentration rating curves (Exhibit 6). Residuals of the rating curves are minimized when only measurements exceeding a threshold of significant sediment transport (about 3,000 cfs) are used. Using measurements greater than the threshold, sediment fluxes were calculated at Cataldo (upstream-most mainstem station) and Harrison (downstream-most mainstem station). Computed sediment fluxes at Harrison are greater than at Cataldo during all but three of the low-flow years (i.e., years when peak flows did not exceed 15,000 cfs). The greater sediment fluxes at Harrison than Cataldo gaging stations during all but the lowest flow years likely reflect the process of sediment being mobilized in the Lower Basin during higher flows.

Differences in the Harrison and Cataldo sediment rating curves reflect differing availability and transport of sediment of different sizes; this difference is particularly evident in the sediment rating curve for sand (Exhibit 6). The much steeper slope of the rating curve for suspended sand at Harrison compared with the other gaging stations implies significant bed erosion between Cataldo and Harrison at higher flows.

Using observational data of bed core stratigraphy, the STM was used to estimate when riverbed erosion occurs. Results indicate that **while some riverbed erosion is expected to occur even during smaller events, widespread floodplain deposition occurs only during the largest events**, when overbank flows transport sediment to the floodplain. One notable pattern seen in the model results is that the upper reaches of the river (below RM 160) generally exhibit net erosion during both overbank flood events and lower flood events, but downstream reaches (below Swan Lake), showed deposition during less-than-overbank events; sediment deposited in these lower reaches during lower flow events gets washed out (either to the floodplain or to Coeur d'Alene Lake) during larger overbank flood events. **For the Thompson Lake to Harrison sub-reach, model runs indicate that this low flow event deposition exceeds erosion that occurred during overbank events, and that the reach has been net depositional over 30 years**.

The channel may continue to adjust to the change in sediment supply by downcutting toward a grade that is consistent with the reduced sediment load. **The long-term trend of riverbed elevation is degradational because more sediment is leaving the Lower Basin than entering from upstream.**

Continued riverbed degradation could potentially result in increasing rates of lead mobilization and transport, because deeper deposits of contaminated sediment generally have higher concentrations of lead. Recent estimates of contaminated sediment deposits in the Lower Basin riverbed (up to several meters) (CH2M, 2017a) and erosion rates (about 1 to 3 cm/year) indicate **erosion and transport of contaminated sediment may continue for hundreds of years in some reaches of the channel**.

The ongoing riverbed response to cessation of mine waste disposal has been degradation in most reaches of the river. **For remedial design, this behavior means that although there is variation between reaches, there is no single source location for contaminated sediments.** Erodible sediments are most commonly sourced from plane bed and dune bedforms, which are distributed throughout the Lower Basin. For this reason, while source control in the upper reaches of the Lower Basin will certainly provide local or even reach-scale benefits, erosion from downstream portions of the riverbed, without source control, are likely to continue to contribute to lead loading. Localized upstream source control may therefore not significantly reduce lead loads in downstream-most reaches or the lake.

2.3.2 Riverbank Response

The initial riverbank response to tailings disposal was aggradation. Overbank flows deposited layers of contaminated sediment up to several meters thick, containing lead at concentrations up to (and exceeding in some locations) 20,000 milligrams per kilogram (mg/kg), in the riverbanks. **The tallest riverbanks observed (which also generally have the thickest deposits of contaminated sediment) are in the upstream Dudley and Cataldo reaches** (CH2M, 2016). **Total bank heights generally decrease in the downstream direction** (Exhibit 7).

After an extended period of riverbank aggradation, erosion began to occur. Erosion of the banks occurs primarily through processes related to fluctuating water levels in the Coeur d'Alene River and Lake. The annual cycle of fluctuating water levels, and the extensive deposits of contaminated sediments, create conditions that limit the establishment of stabilizing vegetation (KSSWCD, 2009). In addition, the lower Coeur d'Alene River attracts recreational boaters in summer months when the lake level is elevated. **Boat waves contribute to erosion of the banks along the entire navigable reach (to RM 160), especially in the lower reaches.** Direct erosion by river flow erodes only portions of the banks during floods.

The lack of stable vegetated banks, boat wave action, and the steep nature of the banks all facilitate bank erosion. Observations (KSSWCD, 2009; CH2M, 2013) indicate that the mode of bank failure is typically by calving of discrete blocks of bank material, which remain at the toe of the bank, acting as transient sediment sources. The supply of contaminants to the river from bank erosion can therefore be considered a gradual, chronic process.

2.3.3 Floodplain Response

The floodplain includes all the lakes, marshes, and upland areas that are bounded by the valley walls. Overbank floods historically delivered (and continue to deliver) contaminated sediments to floodplain areas. **Lead-rich sediments (containing at least 1,000 mg/kg of lead) cover the surface of about 60 square kilometers (km^2) of the 84 km^2 (21,000 acres) of the valley floor** (Bookstrom et al., 2004). These sediments have been deposited in areas of both high and low velocity flow in the floodplain, with varying degrees of connectivity to the river. The total amount of contaminated sediment in the floodplain has a high degree of uncertainty owing to the diversity of environments found there, and because most existing data are spatially focused near the channel.

Floodplain sediment deposition occurs primarily when flow overtops riverbank lines, although exchange also occurs through tie channels into the off-channel storage reservoirs at flows below bankfull stage (approximately 20,000 cfs). Flow into Killarney Lake through the tie channel and over the bank line through Strobl Marsh are major pathways for water and sediment entering the floodplain in the Lower Basin. During large floods, as much as 30 percent of the total river flow may exit the main channel over the right bank line and across Strobl Marsh.

As observed by Bookstrom et al. (2004**), the rate of floodplain deposition was high during the peak mining era and decreased measurably after cessation of direct discharge of tailings in 1968.** The 1980 Mt. St. Helens ash layer (where it is visible in sample cores) provides a time-stratigraphic marker with which to evaluate historical sediment deposition rates versus more recent deposition rates (after 1980) in the floodplain. Analyses of floodplain cores (Box et al., 2001; Bookstrom et al., 2004; CH2M, 2017b) indicate **concentrations of lead in the subsurface tended to be higher than at the surface, and sometimes significantly higher**. Grain size in surface samples generally decreases with distance away from the channel, as larger particles settle faster from the water column. An increasing amount of silt and a decreasing amount of sand are apparent in samples as a function of distance from the main channel, up to about 1 kilometer. Observations also indicate that **the dominant grain sizes in the distal parts of the floodplain are fine silt and clay (less than 16 millimeters [mm]), while the near-channel parts of the floodplain may have as much as 50 percent sand**.

Trends in floodplain deposition rates (Box et al., 2001; Bookstrom et al., 2004; CH2M, 2017b) are likely correlated to trends in sediment supply. For example, floodplain deposition rates likely increase when sediment supply increases because of higher suspended sediment concentrations. Also, more rapid floodplain deposition may be correlated to aggradation of the bed because a higher relative bed elevation would lead to more frequent and longer duration overbank flows. Consequently, the largest sediment fluxes to the floodplain, in the post-mining era, are hypothesized to occur during years with high-flow events and significant floodplain inundation.

The sedimentation rates calculated from floodplain cores (Bookstrom et al., 2004) before and after the large winter 1996 flood event show significantly higher rates of deposition near the channel, indicating higher sediment fluxes to the floodplain during high-flow years. In 1996, exchange with the floodplain from the channel was significant, and had the effect of attenuating peak flow at Harrison. By comparison, the large spring 2008 flood event had a sustained flow with less off-channel attenuation during a larger portion of the flood cycle, resulting in longer and higher flows at Harrison. Thus, it would be expected that **larger, but relatively infrequent, flood events routing large volumes of floodwater out of the channel for longer periods will result in the greatest amounts of floodplain sediment deposition.**

The results of a one-dimensional floodplain sedimentation model corroborate these observations, indicating that 40 percent of the total sediment deposited during the 25-year modeled period (Water Years 1988 to 2012) occurred during the 1996 and 2008 Water Years. Model results also indicate that there is considerable variability in deposition rates by floodplain area (Exhibit 8). The largest estimated mass of sediment is deposited in the off-channel storage areas of the Killarney Lake system (Strobl Marsh, Killarney Lake, and Moffitt Slough), and in Swan Lake. These two complexes —the Killarney Lake and Swan Lake flow systems—are estimated by the model to receive an average of about 6,000 metric tons or more of sediment per year, accounting for more than half the total off-channel deposition in the Lower Basin.

Although **larger flood events are necessary for widespread floodplain deposition, near-channel portions of the floodplain that frequently interact with the channel also exhibit higher deposition rates**. In this context, remedial design should consider recontamination risk within near-channel portions of floodplain areas, wetlands, or lateral lakes, rather than assuming a single recontamination risk over an entire floodplain area.

3.0 Basin-scale Hydraulics and Sediment Transport Characteristics

3.1 Flood Types and Effects on Sediment Transport

3.1.1 Winter versus Spring Floods and Effects on Sediment Transport

The hydrologic regime of the Lower Basin can be characterized by two types of flood events: (1) flashy, winter events, and (2) longer duration spring events. These event types result in important and complex differences in patterns of sediment and contaminant erosion and deposition. **During shorter duration, flashy floods typically generated by winter storms—which commonly begin when lake level is low** and water levels in the Lower Basin lakes and wetlands are low at the beginning of the event**—more water, sediment, and lead are delivered to the floodplain, and downstream flow is greatly attenuated**.

In contrast, **spring snowmelt events—which are characterized by more sustained high flows occurring when lake levels are high,** and water levels in the Lower Basin lakes are also high at the beginning of the event—**are less attenuated between Cataldo and Harrison gaging stations**. Because of the diminished downstream attenuation and longer duration of high flows, snowmelt floods have the potential to mobilize greater quantities of contaminated sediment from the riverbed and deliver it to the lake, over the duration of the flood.

Winter floods may generate higher shear stresses than spring floods of similar magnitude as a result of base level control. During winter months, the level of Coeur d'Alene Lake is lower because of to reduced precipitation runoff in the drainage basin, and removal of flow controls at the Post Falls Dam. Low lake levels can create a higher water surface gradient through all or parts of the Lower Basin, which increases shear stress. In the spring, the backwater effect of the rising lake level reduces the water surface gradient and the resulting shear stress available to mobilize sediment from the riverbed.

Floodplain storage of water is an important factor in modulating flooding and sediment fluxes in the Lower Basin. The shorter-duration February 1996 and January 2011 winter events were significantly attenuated by water entering the floodplain, resulting in a large amount of sediment deposition in the floodplain. In the 2002 and 2008 spring events, sustained flows and resulting higher lake levels (compared with the 1996 and 2011 winter floods) limited the ability of the floodplain to absorb more water during peak flows. However, as larger portions of the floodplain become inundated, more flow is routed to distal portions of the floodplain.

Deposition of sediment during the low flow period, from summer through fall, is enhanced by very low flow velocities throughout the Lower Basin caused by high lake levels. Sediment supplied by multiple processes during low flows is then available for mobilization by the first high flows of the year, which typically deplete this mobile sediment before spring snowmelt occurs. **The magnitude of sediment and lead entering and depositing in the Lower Basin during low flow periods is not well documented but is estimated to be quite low relative to the mass of sediment and lead entering the Lower Basin and eroded from riverbed deposits during high flows.**

Transport and erosion rates (for example, tons per day) of sediment, particularly fines, at Harrison gaging station are generally higher in winter events because of higher shear stress and erosion from the bed, but spring events generally transport more sediment *per event* because of their longer duration.

Flood type is likely to have a discernible effect on suspended sediment concentrations and floodplain deposition, such that the effect of remedial actions, or the river's response to remedial actions, will be different for different types of flood events. Consequently, it is important to characterize river behavior with baseline data sufficient to detect the expected change from each type of flood event.

3.1.2 Types of Floodplain Flow and Sedimentation (Advective versus Diffusive)

Overbank flow across the floodplain is not a uniform process, and hydraulic characteristics of the flow modulates deposition. Diffusive overbank flow areas are near-channel areas where sediment primarily enters the floodplain through dispersive, mixing processes at the interface between the main channel flow and overbank flow. By contrast, advective flow areas are dominated by large, concentrated fluxes of water and sediment exiting the channel and flowing across the floodplain, such as the splays at Black Rock and Strobl Marsh, and the Cataldo Mission floodplain.

There is no apparent difference in overall deposition rates estimated for diffusive and advective flow areas, but the deposition rate patterns are somewhat different. Based on 2016 floodplain core sampling, **deposition rates of 1 to 3 millimeters per year (mm/yr) in diffusive flow areas are more common**, and higher rates are less common. **Deposition rates in the advective flow areas occur in a more bimodal pattern, with rates of 1 to 3 mm/yr and 5 to 15 mm/yr both commonly occurring**. This difference may reflect the relatively small dataset or the concentrated nature of advective flow paths. Identification of advective flow areas in the floodplain should be considered when evaluating recontamination risk.

3.2 Flow Exchange

Primary flow path locations in the Lower Basin are shown in Exhibit 9. These **flow paths occur either as overbank flow areas (generally broad, splay-type locations) or through tie-channels (narrow, stream-like conveyances),** although lateral exchanges between floodplain areas also occur. Another unique characteristic of flow paths in the Lower Basin is the occurrence of "hydraulic blocking," where the downstream gradient of tributary inflows partially blocks contaminant-laden river water from entering these areas. This tributary inflow can influence (and reduce) contaminant deposition in some areas and can have an influence on the system similar to that of the lake level backwater effect. This effect can be especially significant in areas partially protected by levees. While confidence in the occurrence of hydraulic blocking is high, there is lower confidence in the timing and magnitude of this effect because of the uncertainty associated with the hydrologic behavior of individual tributary inflows.

3.2.1 Overbank

Overbank flow is water that exits the river channel over the riverbanks and across the floodplain. T**he greatest influence on** o**verbank exchange is main channel peak flow.** Seasonality and lake level backwater are also strong determinants of overbank flow exchange. Overbank shear stresses are generally low throughout most of the floodplain, based on modeled and observed conditions. Even if most of the floodplain area is inundated during floods, much of this area consists of slow-moving or standing water. Consequently, **overbank flows in the floodplain are almost exclusively depositional, rather than erosional**.

Sediment deposition in the floodplain is greatest when it occurs as through-flow—that is, floodwater that enters the floodplain and then exits further downstream. Longer duration flood events maximize the time that through-flow (and deposition) can occur.

3.2.2 Tie Channels

Tie-channels are narrow, stream-like conveyances, generally incised into the floodplain, between the river and the floodplains. They have invert elevations below that of the floodplain and consequently experience more frequent low-level flow exchanges. Several tie-channels in the Lower Basin provide year-round pathways for exchange between the river and the floodplain (Exhibit 9), including those at Killarney Lake, Swan Lake (two), and Medicine Lake.

The flow dynamics of tie channels have been modeled by the STM and parameterized with a dataset of paired water level logger observations. A model simulation of a 30-year period of record indicates that **most flows to off channel areas are by tie-channels during low and moderate flows, and by overbank flow during larger (20,000 cfs and greater) events**. Model results indicate that more flow enters Swan Lake by overbank flow than by tie channel. For more frequent events, the Killarney tie-channel conveys as much or more volume of water than overbank flow. During large floods, f**low into Strobl Marsh over the bank line and into Killarney Lake through the tie channel are major pathways for water and sediment entering the floodplain in the Lower Basin.**

3.3 In-channel Fate and Transport of Sediment and Lead

The movement of sediment and lead through the channel is related to multiple factors, and various types of sampling have been conducted to delineate these factors. Physical samples of mobile sediment have been collected at several locations, commonly USGS gaging stations, for different periods of record and at different river conditions, and focused sampling has been conducted more recently from bridges and boats to provide spatial distribution of sediment and lead concentrations during flood events. Bridge-based samples have a longer period of record but lack the spatial resolution of boat-based (between bridges) sampling. Riverbed cores have also been collected throughout the Lower Basin to determine depth and extent of contaminated sediment (CH2M, 2016). These data were synthesized to answer the following questions.

3.3.1 Where is the Sediment and Lead?

In-channel measurements of suspended sediments and riverbed cores show that contaminated sediments are pervasive in bed sediments, are generally more contaminated with greater depth, and are mobilized from the bed at flows exceeding a transport threshold discharge.

Suspended sediment concentration (SSC) rating curves (Exhibit 5) developed from **suspended sediment samples at bridges show that more sediment is going out past the Harrison gaging station then is coming in past the Cataldo gaging station**. Consequently, sediment is being sourced between those two stations. Bathymetric and repeat cross-section analysis shows that an overall signal of bed lowering also confirms that the channel (bed and banks, but chiefly the bed) is the primary source of sediment and lead.

Measurements of lead in suspended sediments collected by boat-based grab sampling during large spring floods in 2012 and 2017 (Exhibit 10) also show that lead concentrations increase monotonically, by a factor of approximately 5, from the Old Mission boat launch near Cataldo (RM 160) to the Bull Run bridge near Rose Lake (RM 147). The increase in lead and SSC through this reach indicate that a primary source of sediment and lead is the riverbed**. Downstream of RM 147, both lead concentration and SSC flatten or slightly decrease as overbank flow enters Strobl splay and the floodplain.** Lead concentrations and SSC remain roughly flat to the Harrison gaging station.

However, riverbed cores also show elevated lead concentrations in the Killarney and Springston reaches (Exhibit 11). The spatial distribution of lead in riverbed cores shows that contaminated sediments are sourced throughout the riverbed in the Lower Basin. Consequently, **remedial actions to prevent bed erosion may only result in a local decrease in lead concentrations in suspended sediments**, as erosion of downstream portions of the bed may increase following upstream source control actions.

These corroborating observations indicate that **the riverbed is the source of most of the mobile sediment and lead stored in the system. The sediment deficit between the Cataldo and Harrison gaging stations indicates that the river appears to be gradually eroding through legacy deposits of contaminated sediment stored in the bed.** The sediment deficit in between Cataldo and Harrison, along with the other sediment budget components (discussed in section 3.5), imply that riverbed is degrading.

Lead concentrations in contaminated sediments are generally higher in the finer (silt/clay fraction) bed sediments (Exhibit 12). However, the correlation between lead and grain size for contaminated sediments is only general. **Among contaminated sediment samples, there is almost an order-of-magnitude range in lead concentration for a given grain size**. This pattern of variability suggests that **grain size is not the primary control for lead concentration in riverbed sediments**. Mineralogical analysis of contaminated sediments supports the hypothesis that lead content is more strongly correlated to the origin and history of the deposit, meaning the mining method that produced the waste and the grain size associated with specific mine waste products. **Lead in sediments in the Coeur d'Alene River is not generally bound to the surfaces of sediment but instead is often part of the particle, rather than sorbed to the surface**. This difference tends to reduce the grain-size control of lead concentration; and because particles of different grain size may have similar mineralogical characteristics, all other things being equal.

Because of the great variation in milling and waste disposal practices during the era of active mine waste discharges into the rivers (Bookstrom et al., 2004), contaminated bed sediments have a wide variation in thickness, grain size, and concentration. Consequently, while lead concentrations of post-mining deposits increase with decreasing grain size, grain size is not the primary control on the lead concentration of riverbed sediment. Instead, **the age of the deposits is the most important factor determining lead concentration**.

3.3.2 Where are Sediment and Lead Going?

Spatial trends in SSC indicate the locations of sediment and lead sources and sinks in the Lower Basin. A comparison of rating curve slopes at the Cataldo and Harrison gaging stations show that more sediment is being transported past Harrison than is coming into the river at Cataldo. On average, **once mobilized, most of the contaminated sediment that is eroded from the riverbed enters Coeur d'Alene Lake**, but a substantial fraction also enters the floodplain (during large floods) and is deposited there. Specific fractions of lead and sediment routed to the lake and floodplain are discussed in the context of the sediment and lead budget (Section 3.5).

3.3.3 Lead Concentration Correlations

Downstream trends in SSC show that SSC increases with increasing discharge (Exhibit 6), which indicates sediment mobility occurs through the Lower Basin. However, there is not a direct relationship between SSC and Pb concentration in suspended sediment (Exhibit 13). As illustrated in Exhibit 13A, for different locations, **lead concentration does not monotonically increase as SSC increases -** and as shown in Exhibit 13B, **lead concentration does not show a clear trend with increasing discharge (while SSC does)**. **Lead concentration does increase with decreasing lake level** (Exhibit 13C), as measured at the Harrison gaging station**. These data represent flows ranging from 7,000 to 22,700 cfs, with a median value of 17,400 cfs.** This trend of increasing lead concentration with decreasing lake level supports the hypothesis that more bed erosion occurs when the lake level is lower, creating steeper water surface gradients and higher shear stresses. Exhibits 13A and 13B show **that lead concentration in suspended sediments is dominantly a function of location in the Lower Basin, and that lead concentration increases in the downstream direction**. The lack of correlation of lead concentration with either SSC or discharge indicates that contaminated sediments are readily mobilized by a wide range of flows. For remedial design, this behavior indicates that contaminated sediment transfer from the riverbed is a frequent process, and spatially limited remedies will result in spatially limited changes in lead concentration.

3.4 Floodplain Fate and Transport of Lead

3.4.1 How and When does Lead Enter the Floodplain?

Contaminated sediment enters the floodplain via tie channels and overbank flooding. **The greatest influx of lead-contaminated sediment occurs when flood conditions facilitate through-flow of floodwaters into, across, and then out of the floodplain**. The transfer of contaminated sediment is limited when floodplain storage is filled and through-flow into and out of the floodplain is partially blocked, or when a single conveyance connection to the river limits the volume of floodwater, and accompanying contamination, to enter and deposit. However, contaminated floodplain sediments have been found even in distal portions of the floodplain, likely from deposition occurring at the largest floods.

Estimating sedimentation rates from floodplain data is difficult without a time-stratigraphic marker of a known date. An ash layer from the eruption of Mt. Saint Helens in 1980 is observable in some floodplain core samples and provides such a marker. This reference point has been used to estimate floodplain sedimentation rates before and since 1980, but the samples containing the ash layer are relatively limited and not well distributed (the ash layer is rarely visible in lakes, or floodplain areas that were inundated at the time of the eruption). To better extrapolate post-1980 sedimentation rates to larger portions of the Lower Basin, a one-dimensional floodplain sedimentation model was used. The model uses discharge, suspended sediment concentration, and trapping efficiency to calculate sediment fluxes into delineated floodplain areas and estimates the proportion of the sediment flux that could settle and remain in the floodplain. A 25-year period of record (Water Years 1988 to 2012) was used. The **model results indicate that the highest estimated floodplain sedimentation rates occurred in 1996, 1997, 2002, 2008, 2011, and 2012, with these 6 water years (24 percent of the flood seasons) accounting for 78 percent of the total mass deposited in the floodplains over 25 years**. In other words, short periods of overbank **flooding during one quarter of the water years appear to account for three quarters of the sediment deposition in the floodplain**.

3.4.2 Where is the Lead Going?

As part of the Basin Environmental Monitoring Program (BEMP), depositional samples have been collected (2011 to 2017) using tiles placed in the floodplain and stakes placed near the riverbanks. These annually monitored data (Exhibit 14, summarizing data through 2017) show a sharp increase in lead concentration from the Cataldo dredge pool (RM 160) downstream through the Dudley reach, as overbank flows enter the floodplain. Lead concentrations show a wide range of variation through the Dudley reach and downstream to Anderson Lake, reflecting multiple driving factors such as lake level, flood type (winter versus spring), peak attenuation, and available floodplain storage. The effect of flood type is also seen in the variation of lead concentrations, over time, at the same sampling stations (Exhibit 15). Stations near the Killarney/Strobl complex show the greatest variation.

Observed data show that **lead is deposited in floodplain landforms that commonly interact with the active channel** (Exhibit 16); **landforms like riverbank wedges (created by near channel deposition), sand splays, natural levees, and distributary channels have the highest lead concentrations of all floodplain landforms. Recontamination risk is higher for landforms that have higher inundation frequency**, even when bankfull discharge is not reached. This tendency is reinforced by a statistical "hot spot" analysis (Exhibit 17) that shows that statistically significant clusters of high lead values are located in the same landform types.

Areas subject to through-flow, advective flow, or frequent interaction with the river, show a similar spatial pattern, with higher levels of modeled and observed lead concentrations (Exhibit 18, showing surface samples taken from data collection performed in 2007, 2008, 2015, and 2016. These interactions with the river may occur even when overbank flooding is not occurring.

For remedial design, high spatial resolution of data monitoring is needed to identify a signal change in the floodplain resulting from source control. Monitoring in near-channel floodplain landforms, pre- and post-remedial action, may provide initial indication of effectiveness given the more frequent pattern of inundation and deposition in these areas, as well as identify areas with the greatest recontamination risk.

3.5 Sediment and Lead Budgets

An overall sediment and lead budget has been developed to provide a framework for understanding the primary geomorphic processes driving the sources and pathways of contaminated sediments in the Lower Basin. Understanding the relative proportion of key factors such as bank and bed erosion and sediment transport rates is important for recognizing the potential impact of remedial actions on the mobility of contaminated sediments.

The sediment and lead budgets are conceptualized (Exhibit 19) as <u>sources</u>, including influx from upstream, erosion of the bed, and erosion of the banks; and <u>sinks</u>, where mobilized sediment and lead are deposited, either in the floodplain, or in Coeur d'Alene Lake.

The total sediment flux for the Coeur d'Alene River was computed using the bulk sediment rating curves for each USGS gaging station (Pinehurst, Enaville, Cataldo, and Harrison) and the discharge record at the gages. Similarly, the flux of sand (bed material load) and fine (wash load) fractions were also computed using the rating curve regressions for the corresponding grain size fractions. **Fines are the dominant fraction at Pinehurst (South Fork), Enaville (North Fork), and Cataldo. At Harrison, the relative**

proportions of fines and sand fluctuate from year to year, with a higher proportion of sand being moved during years with higher flow. Consequently, while both fines and sand are mobilized at high flows in the Lower Basin, **more sand is mobilized than fines as flows increase. In higher flow years, sand accounts for about half of the sediment flux at the Harrison gaging station**.

Sediment rating curves rely on a power law relationship between suspended sediment concentration and discharge. However, residuals in the regression indicate that other factors have a significant influence on predictions of SSC. An alternative multiple regression rating curve was developed that predicts SSC as a function of the level of Coeur d'Alene Lake at the time of measurement, as well as discharge. Accounting for the lake level in the rating curve, in addition to discharge, reduces the residuals between predicted and observed SSC, especially for samples collected at higher flows. The revised estimate of the average annual sediment transport rate at the Harrison gaging station was 25 percent lower using the multiple regression rating curve than initial estimates. Lead concentrations from suspended sediment samples were used together with SSC and discharge to estimate lead flux in (at the Cataldo gaging station) and out (at the Harrison gaging station).

Using bedform mapping of the riverbed and the results of 2013 Vibracore bed sampling, estimates of the total amount of contaminated sediment present in the riverbed were calculated. Where coring did not reach the base of contaminated sediments, a maximum depth of contamination between 6 and 15 feet was assumed to bracket estimates of the volume of contaminated sediment. The resulting sediment mass was estimated at 6 to 13 million metric tons, depending on the assumed thicknesses of sediments in the dune and planar bed areas. Assuming a typical lead concentration of 5,000 mg/kg, the contaminated riverbed sediment would contain between 30,000 and 65,000 tons of lead. The annual rate of sediment erosion is estimated at 35,000 metric tons, and the annual rate of lead erosion at 180 metric tons (Exhibit 19).

Lead flux from riverbanks was calculated using bank length, percent eroding bank, average bank height, thickness of contaminated portion of banks, rate of bank erosion, and average lead concentration in contaminated banks. The estimated average mass of sediment mobilized by bank erosion in the Lower Basin is about 8,000 metric tons per year, and about 32 metric tons per year of lead (Exhibit 19).

The estimated annual rate of sediment delivery to the floodplain was estimated using both core-based deposition rates and estimations of the one-dimensional floodplain sedimentation model. Core-based estimates are 7 to 8 times higher than model estimations, likely due to the locations of core sampling (typically in areas of expected high deposition). Because of sparseness and likely bias of the sampled cores, model results were used for the budget estimate, resulting in an estimated annual sediment deposition of about 24,000 metric tons, and lead deposition of 68 metric tons per year.

Using these analyses, the annual flux from sediment and lead sources (riverbed, riverbanks and inflow) and flux into sinks (floodplain and Coeur d'Alene Lake) were calculated and are summarized in Exhibit 19. **The sediment and lead budget confirm that the primary source of mobile lead in the Lower Basin, now and in the future, is contaminated sediment stored in the riverbed.**

The STM generally corroborates the sediment and lead budget based on observed data (Exhibit 19**). Model results indicate that the dominant source of lead erosion is the flat portion of the channel bed; side slopes are typically neutral or depositional. Modeled changes in bed elevations also show that the Dudley Reach is the largest source of lead. The amount of lead mobilized downstream of Dudley Reach is generally more uniform among reaches**. Overall, the lead budget values calculated by both approaches indicate that most of the lead transported in the Lower Basin originates within the sand-bed reach of the river.

The calculation of sediment and lead *flux*, while important in understanding and managing contaminant migration, requires multiple poorly constrained variables, and therefore has relatively higher uncertainty. In contrast, lead *concentration* in suspended and depositional sediments may be the most reliable means to measure and evaluate remedial effectiveness.

4.0 Reach-scale Hydraulics and Sediment Transport Characteristics

Hydraulic characteristics vary longitudinally through the Lower Basin. For example, the channel type changes (and the slope decreases at the Cataldo dredge pool (RM 160), and flow in the channel varies as water is routed to (and back from) off-channel storage during flood cycles and as lake levels affect river stage conditions. These variables result in different hydraulic and sediment transport conditions in different reaches. General trends in longitudinal variation and specific reaches, as identified by the STM, are discussed in this section.

At the reach-scale, model results indicate that during peak flood events, channel shear stress is relatively consistent longitudinally throughout the Lower Basin (below RM 160). However, shear stresses are longitudinally more variable during flashy events such as the modeled January 2011 event, when the rapidly rising water levels in the channel create a steeper gradient to low lake elevations. Model results show that shear stress generally decreases in the downstream direction, especially below about RM 148 near Strobl Marsh, where under flood conditions significant flow exits the channel into the Killarney Lake complex, and where downstream lake levels have the greatest effect on water surface gradients. The impact of backwater on shear stress becomes more muted from RM 150 to RM 160 and is nearly absent upstream from RM 160.

Bed erosion is also variable by reach. Although the riverbed of the Cataldo, Killarney, and Springston reaches is net erosional, model results show that the Killarney reach has the greatest rate of bed erosion, while the Springston reach has the least. This result is consistent with analyses using observed data (Exhibit 5). The Springston reach is most affected by the lake backwater effect, which buffers erosive hydraulic forces and facilitates more deposition during slack-water periods (summer through fall). The Killarney reach is affected to a lesser degree by backwater, but lake level variation has a pronounced effect on flood peak attenuation and subsequent erosion of bed sediments. If lake levels are low, greater water surface slope will enhance erosion of bed sediments.

The STM and observational data indicate that floodplain deposition varies longitudinally. Floodplains that receive the largest amounts of sediment are those that that have high through-flow of floodwater—that is, those areas that have an upstream inflow directly or indirectly from the channel, and a downstream outflow back to the channel. Floodplains with through-flow have a continuous source of sediment and lead into the floodplain via the floodwaters, and function with varying degrees of efficiency as sediment traps. Floodplains and lateral lakes that have only a single hydraulic connection to the river receive much less sediment and lead because they receive only a single inflow volume of floodwater, and the sediment and lead contained in that inflow volume (i.e., they fill with water during the rising limb of the hydrograph and then stop exchanging water and sediment during the flood and drain on the falling limb). The following examples compare flood dynamics and sediment deposition for different off-channel areas in the Lower Basin. These areas, and recontamination risk, are affected by floodwater through-flow, and their characteristics vary depending on their location in the Lower Basin and the number and type of their hydraulic connections to the river.

4.1 Example 1: Strobl Marsh/Killarney Lake/Hidden Marsh/Moffit Slough Complex

This complex is characterized by its large off-channel storage capacity. During floods, as much as 30 percent of the total river flow may exit the main channel and enter Strobl Marsh (and Killarney Lake) over the bank line and into Killarney Lake through the tie channel. This is a major pathway for water and sediment accessing the floodplain in the Lower Basin. Floodplain sampling also shows that measured deposition rates in this area were highest along the natural levee bordering the Killarney Lake tie channel and at the splay at Strobl Marsh. The deposition rate was measured on the natural levee formed along the Killarney Lake tie channel at more than 16 mm/yr—the highest of any location sampled during the 2016 floodplain sampling effort (Exhibit 20). Deposition rates exceed 10 mm/yr along the natural levee and in parts of the Strobl splay area, presumably reflecting the large fluxes of water over these areas during floods. Grain sizes decrease with distance from the channel in the Strobl Marsh area.

4.2 Example 2: Swan Lake Floodplain Area

Swan Lake is located relatively low in the Lower Basin (at RM 139 to RM 142), and consequently is more directly influenced by lake levels and by upstream floodplain attenuation. During winter events, Swan Lake experiences overbank flow relatively infrequently but receives overbank flows more commonly during spring events.

The lake is hydraulically connected to the river via two tie-channels (east and west), via Blessing Slough (an incised floodplain channel that runs parallel to the main channel) and Blue Marsh downstream, and via overbank flow during floods. Overbank flow and Blessing Slough are the primary sources of water and sediment to Swan Lake and its floodplain.

Model results of the STM indicate that most sediment and lead influx is by overbank flow exchange. However, most influx is split between Blessing Slough and overbank flow. During winter flood events, Blessing Slough is the primary flowpath but in spring floods, overbank flow is the primary flowpath. For sediment and lead fluxes, overbank flows provide most of the sediment, but the primary flowpath for lead is roughly split between the east tie channel and overbank flow.

There are multiple pathways for through-flow in the Swan Lake area that create the risk of frequent deposition and recontamination. A 30-year STM run indicates that Swan Lake experiences sediment deposition exceeding 1 ton for all the years in the 30-year modeled period; 93 percent of the years exceed 10 tons; 83 percent of the years exceed 100 tons; and 50 percent of the years exceed 1,000 tons**. The potential for ongoing deposition (recontamination) in the Swan Lake area is considered high**.

4.3 Example 3: Black Rock Slough Area

The Black Rock splay area lies at RM 151.7 on the outside (left) bank adjacent to a sharp bend in the river, where a deep scour hole has formed. During floods, large amounts of flow exit the channel at this location, creating a splay (i.e., a landform characterized by overbank flow and deposition of sediment in an outward tapering pattern) across the meander peninsula, before returning to the channel.

Black Rock Slough is south of the Black Rock splay and is hydraulically separated from the river by the trail of the Coeur d'Alenes embankment; it has limited connectivity with the main channel. Primary flood stage interaction with the river at Black Rock Slough occurs via overbank flow across Black Rock splay, which then connects with Black Rock Slough via a tie-channel beneath a bridge on the trail, and by off-channel inflow from Bull Run Lake.

During normal flow conditions, Black Rock Slough does not exchange water with the main channel. The tie channel invert is below the median river surface elevation (exceeded 50 percent of the time, based on the 30-year simulation) but is not connected to the river until it reaches higher elevations because of the hydraulic barrier of Black Rock splay floodplain. The tie-channel is activated during most large events.

Black Rock Slough is fed by tributary inflows with a catchment area of approximately 4.5 square miles. This moderately-large tributary area and the associated tributary flow contributes to perirheic mixing and hydraulic blocking. When this tributary flow is artificially removed from the STM, river flow into Black Rock Slough increases by about 80 percent for the modeled January 2011 event.

Owing to its infrequent connection to the river, Black Rock Splay receives most of its sediment during large events. On an area-normalized basis, the STM results indicate that Black Rock Slough receives about 30 percent less sediment deposition, averaged over 30 years, than Swan Lake.

Compared to Swan Lake, Black Rock Slough has a lower risk of recontamination. The STM results show that sediment deposition in Black Rock Slough exceeds 1 ton in only about 40 percent of water years, meaning that most of the sediment deposits during only the largest flood events. About 80 percent of the total 30-year sediment mass was deposited over four events (February 1996, April 2002, May 2008, and March 2017). **Because the tie channel is the primary conduit for sediment, it can be modified by flow control structures to limit recontamination risk**.

5.0 STM Characterization of Future River Behavior (30-year Model Run Assuming No Remedial Action)

The STM was used to model long-term behavior of the river for a 30-year period to assess changes that may occur if no remedial actions were performed. Many of the results parallel trends in observed data for specific flood events (Exhibit 21), but also provide a means to compare winter and spring events.

In general, similar to observational data, the STM shows that sediment and lead mobility is episodic in that most erosion and deposition occurs over a period of a few days during large flood events. While it is tempting to describe long term "trends" as annual averages, this can be misleading.

Over a simulated 30-year period, the average fluxes of sediment and lead from the riverbed were similar for spring and winter events:

- 33 kilotons sediment and 210 tons lead for average spring events
- 40 kilotons sediment and 200 tons lead for average winter events

Model results also show that erosion occurs during large and small events, but extensive floodplain deposition occurs only during large events, when overbank flows transport sediment to the floodplain. Spring events are much less erosional, and often even depositional. Model results show that about 45 percent of long-term deposition occurs during longer spring events, and about 40 percent occur during winter events. **When sediments are mobilized from the riverbed, 30 to 40 percent of sediments are deposited on the floodplain and 60 to 70 percent are transported to the lake.**

6.0 Future Revisions to the Conceptual Site Model

The information summarized in the preceding sections represents a compilation of available data, analyses, and modeling output of key characteristics of the Lower Basin of the Coeur d'Alene River. As additional data are collected from ongoing monitoring and remedy design efforts, refinements to the conceptual site model are expected. Many of these refinements will likely provide increased resolution of the patterns of transport and deposition of contaminated sediments, both in the river channel and in off-channel habitat areas. Other revisions may also be made as data are obtained over longer periods of time, and represent more flood cycles, types, and magnitudes, or as modeling simulations identify additional patterns or trends.

While continued data collection and analysis is expected to improve conceptual site model resolution and certainty, the Lower Basin will also remain in a state of continual change for decades to come, from natural responses by the river system to post-mining conditions and from remedial actions implemented in the system. Ongoing data collection, analysis, and modeling will provide the basis for improving the understanding of the nature and rates of change occurring in this complex and evolving system. The Synopsis will be updated periodically, as such updates are available and appropriate, to reflect these changes.

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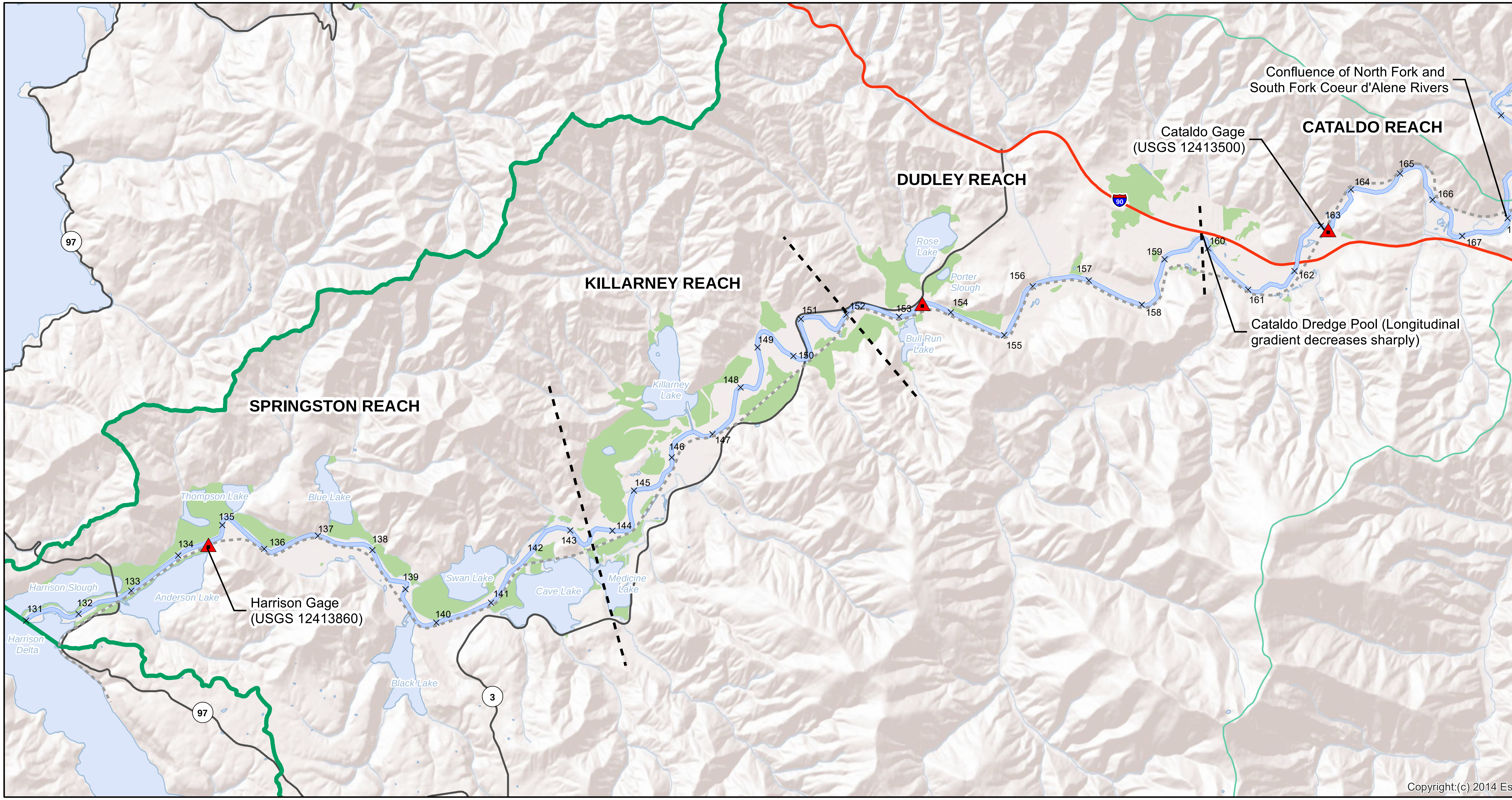

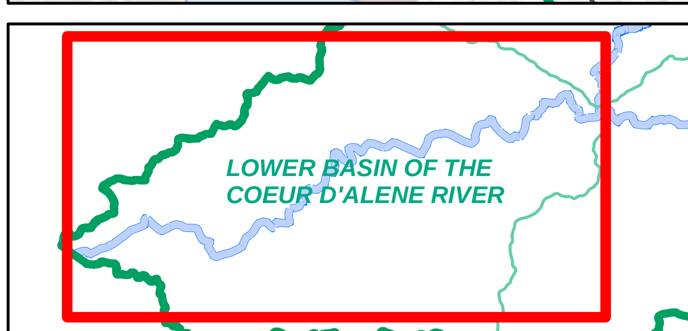

LEGEND

- City
- River Mile Marker
- USGS Gaging Locations
- Interstate Highway
- Highway
- Trail of the Coeur d'Alenes
- Reach Divides
- Coeur d'Alene Watershed
- Waterbody
- Marsh or Slough

N

0 1 2 4 Kilometers

Exhibit 1. **Lower Basin Overview Map**
Synopsis
Lower Basin of the Coeur d'Alene River (OU3)

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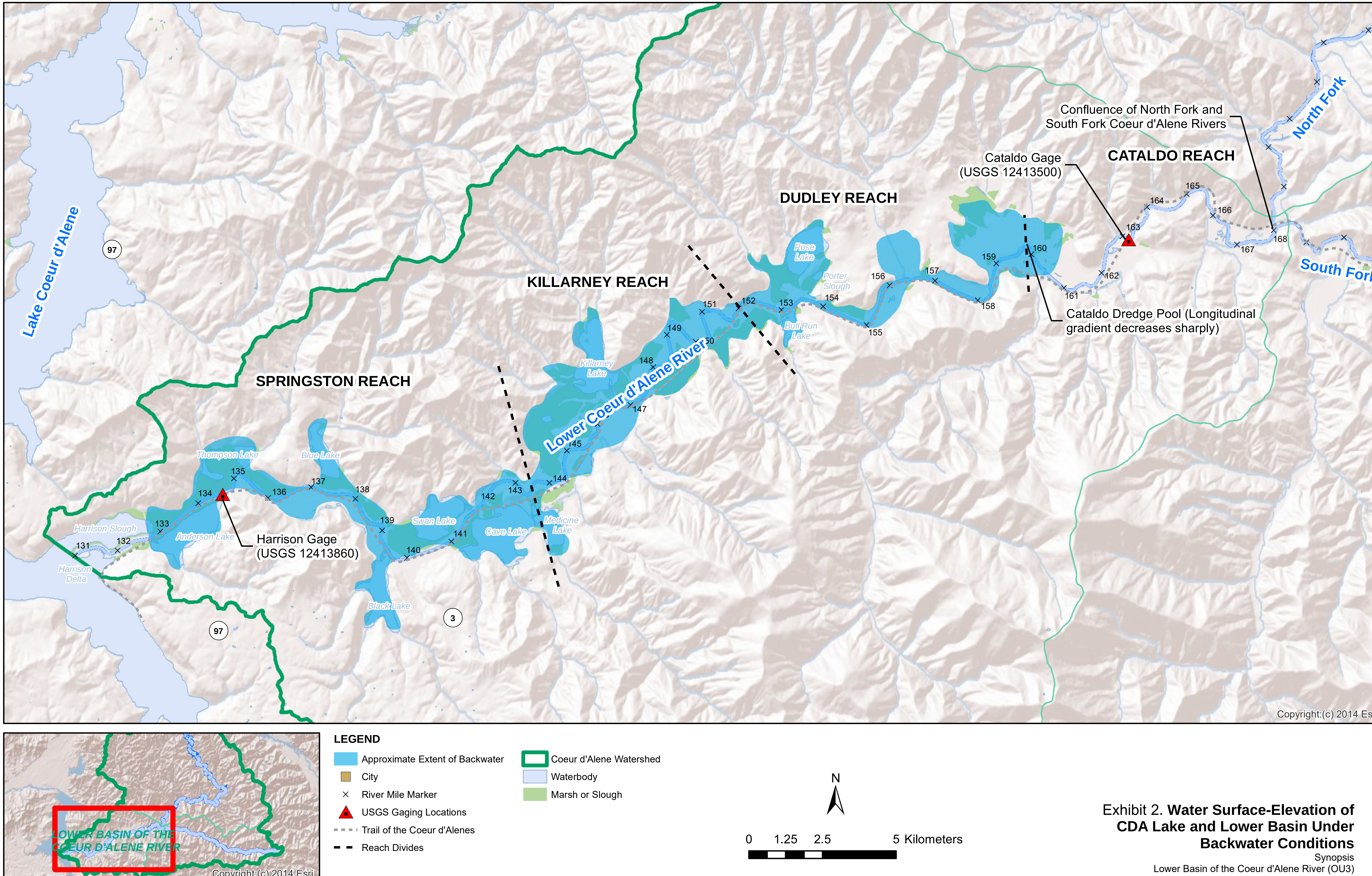

Exhibit 2. **Water Surface-Elevation of CDA Lake and Lower Basin Under Backwater Conditions**

Synopsis

Lower Basin of the Coeur d'Alene River (OU3)

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Exhibit 3. **Flood Event Definition**
Synopsis
Lower Basin of the Coeur d'Alene River (OU3)

Event Name	Start Date/Time	End Date/Time	Event Duration (days)*	Event Volume (at Cataldo, acre-feet)	Starting Lake Level (ft)	Cataldo Peak Flow (cfs)	Harrison Peak Flow (cfs)	Event Type
January 1990	1/7/1990 0:00	1/16/1990 0:00	9	198,140	2124.64	28,300	16,362	Winter
November 1990	11/24/1990 12:00	11/29/1990 12:00	5.00	166,716	2127.30	33,400	19,802	Winter
February 1991	2/5/1991 6:00	2/27/1991 0:00	21.75	317,922	2124.74	24,400	13,949	Winter
April 1991	4/1/1991 0:00	4/14/1991 0:00	13.00	234,345	2125.75	24,700	18,175	Winter
February 1995	2/19/1995 0:00	2/25/1995 12:00	6.50	214,860	2126.44	32,400	19,162	Winter
December 1995	11/24/1995 0:00	12/11/1995 0:00	17.00	376,175	2127.66	32,800	20,006	Winter
February 1996	2/6/1996 0:00	2/17/1996 6:00	11.25	391,831	2125.07	69,302	33,336	Winter
April 1996	4/23/1996 6:00	5/12/1996 0:00	18.75	304,453	2128.87	31,100	15,218	Spring
April 1997	4/16/1997 18:00	6/24/1997 0:00	68.25	1,505,400	2127.69	26,400	20,133	Spring
April 2000	4/10/2000 0:00	4/27/2000 12:00	17.50	470,335	2128.38	28,700	18,746	Spring
April 2002	4/6/2002 18:00	4/20/2002 0:00	13.25	385,053	2126.90	37,102	26,230	Spring
February 2003	1/26/2003 6:00	2/9/2003 0:00	13.75	213,258	2123.16	23,600	11,545	Winter
March 2007	3/11/2007 12:00	3/17/2007 18:00	6.25	157,483	2125.79	23,900	14,500	Winter
May 2008	5/14/2008 18:00	7/27/2008 0:00	73.25	1,086,960	2130.61	31,300	27,900	Spring
January 2011	1/14/2011 0:00	1/25/2011 6:00	11.25	264,521	2124.28	32,800	18,800	Winter
May 2011	5/2/2011 0:00	6/2/2011 0:00	31.00	742,805	2128.25	23,000	17,400	Spring
March 2012	3/26/2012 0:00	4/9/2012 12:00	14.50	292,424	2126.90	28,700	17,500	Winter
April 2012	4/20/2012 12:00	5/8/2012 0:00	17.50	515,285	2130.09	26,200	20,400	Spring
March 2014	3/5/2014 0:00	3/16/2014 18:00	11.75	297,502	2123.65	28,901	18,401	Winter
February 2015	2/7/2015 0:00	2/17/2015 0:00	10.00	269,792	2126.28	24,001	16,301	Winter
March 2017	3/10/2017 0:00	4/12/2017 0:00	33.00	821,336	2126.25	33,701	22,500	Spring

* The total time of the defined events in this table make up 3.9% of the total simulated 30-year period (sum of event durations / 30-year simulation period = 0.039). Criteria for defining events, including the start and end time, are described in Section 2.1.1 of TM D-5.

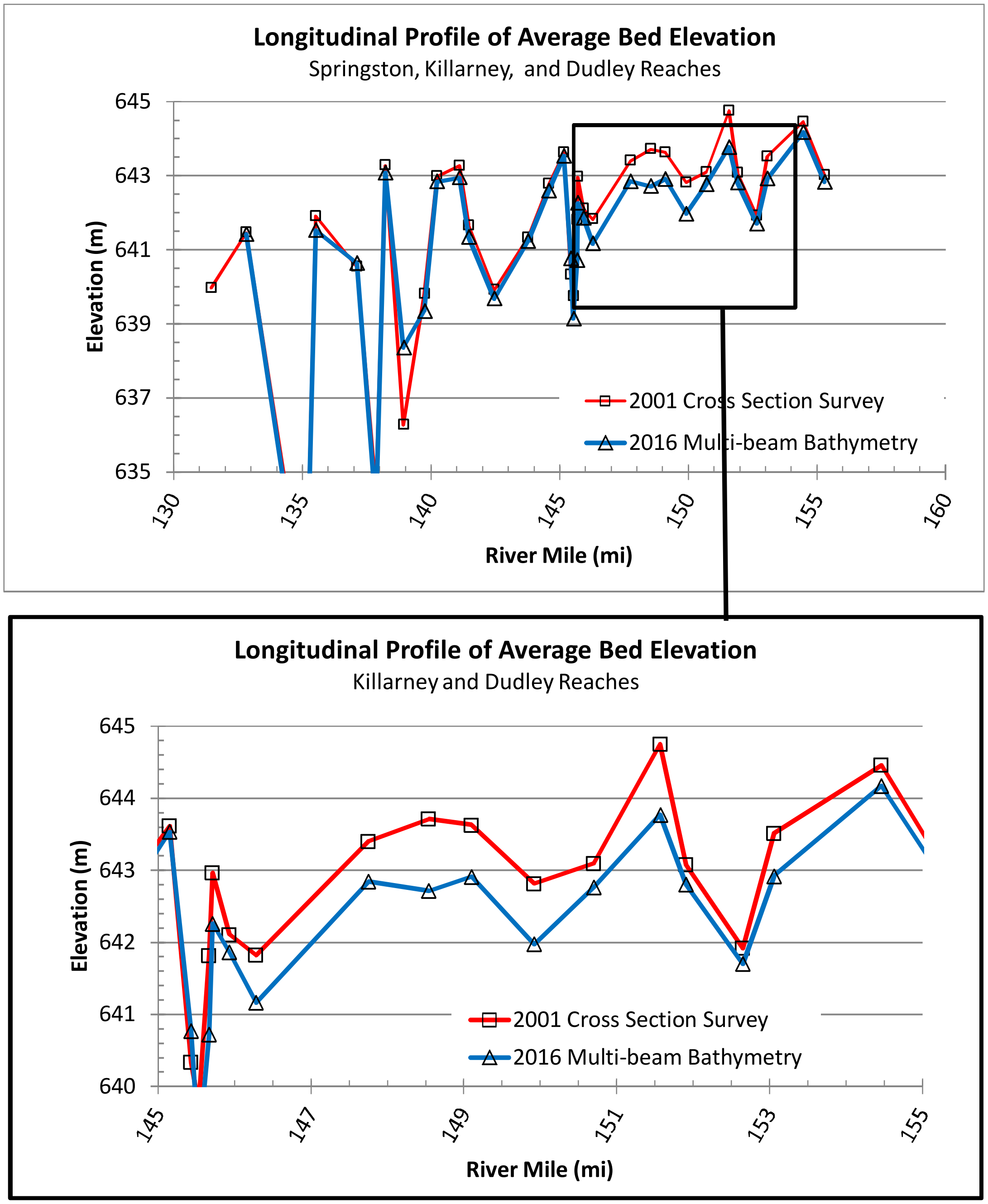


Exhibit 4. **Longitudinal Profile of Average River Bed Elevation (from Surveyed Cross-Sections and Bathymetric Survey) at Selected Cross-sections in 2001 and 2016**

Synopsis

Lower Basin of the Coeur d'Alene River (OU3)

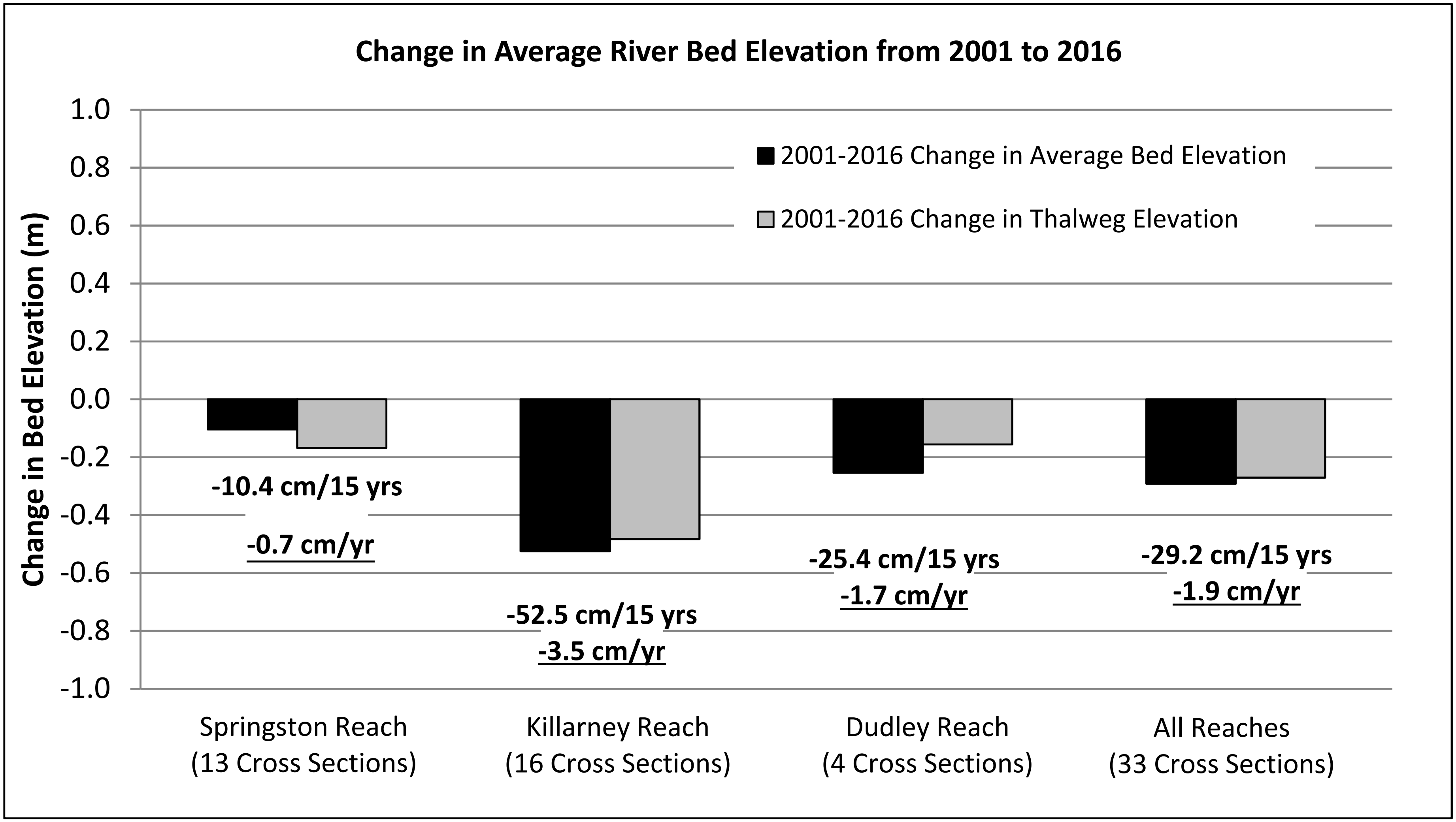
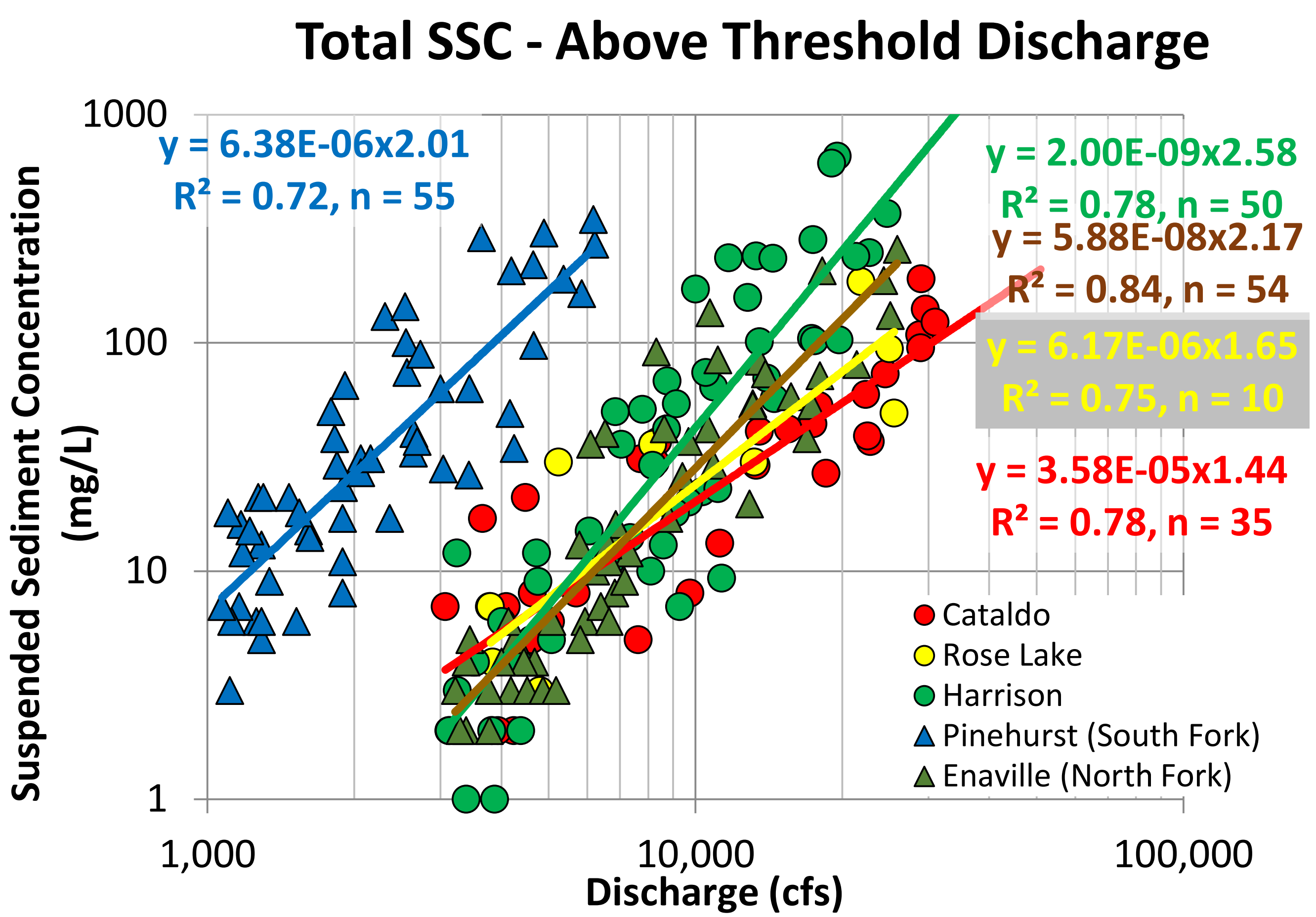


Exhibit 5. **Change in Average River Bed Elevation from 2001 to 2016**



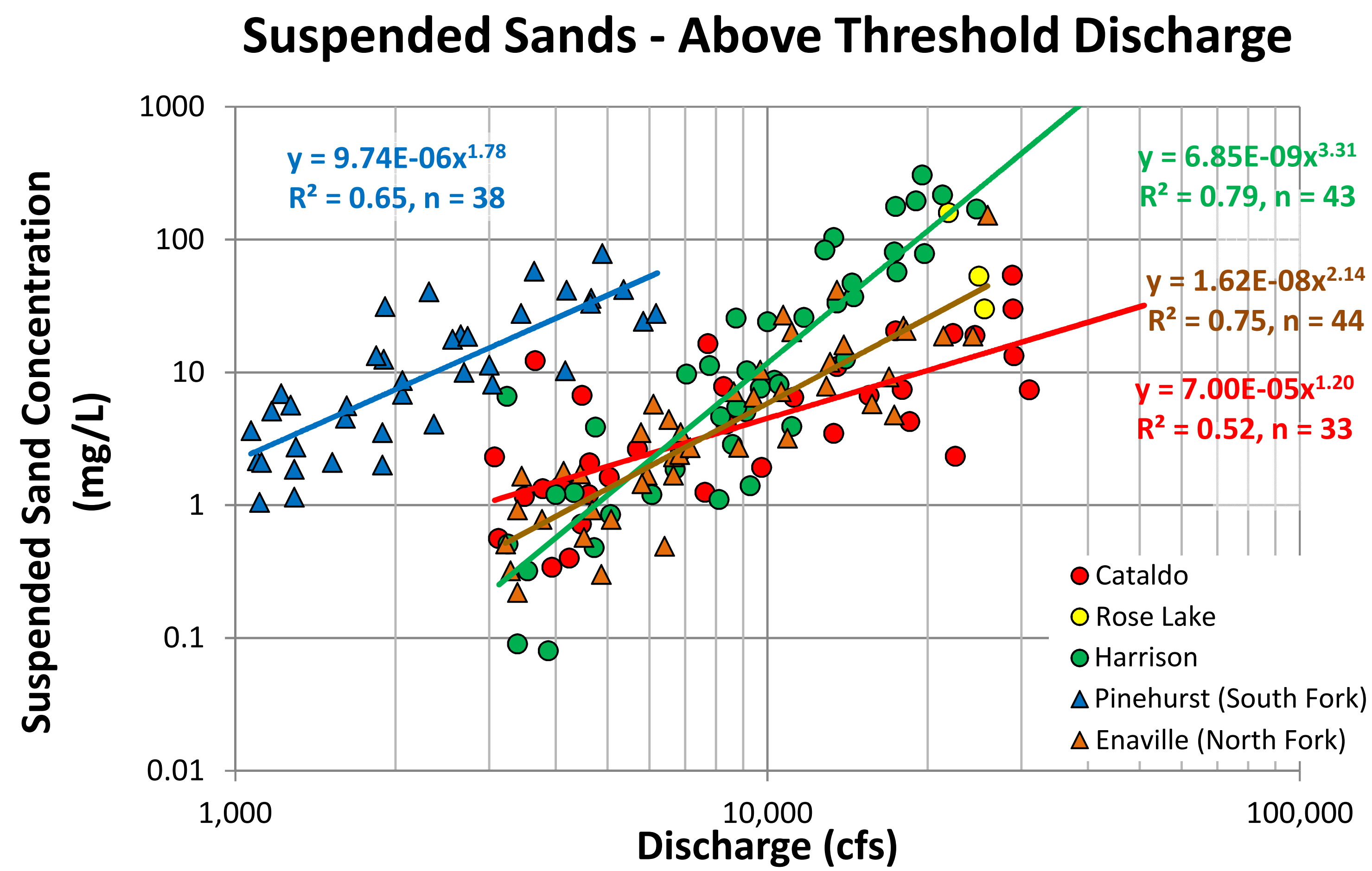
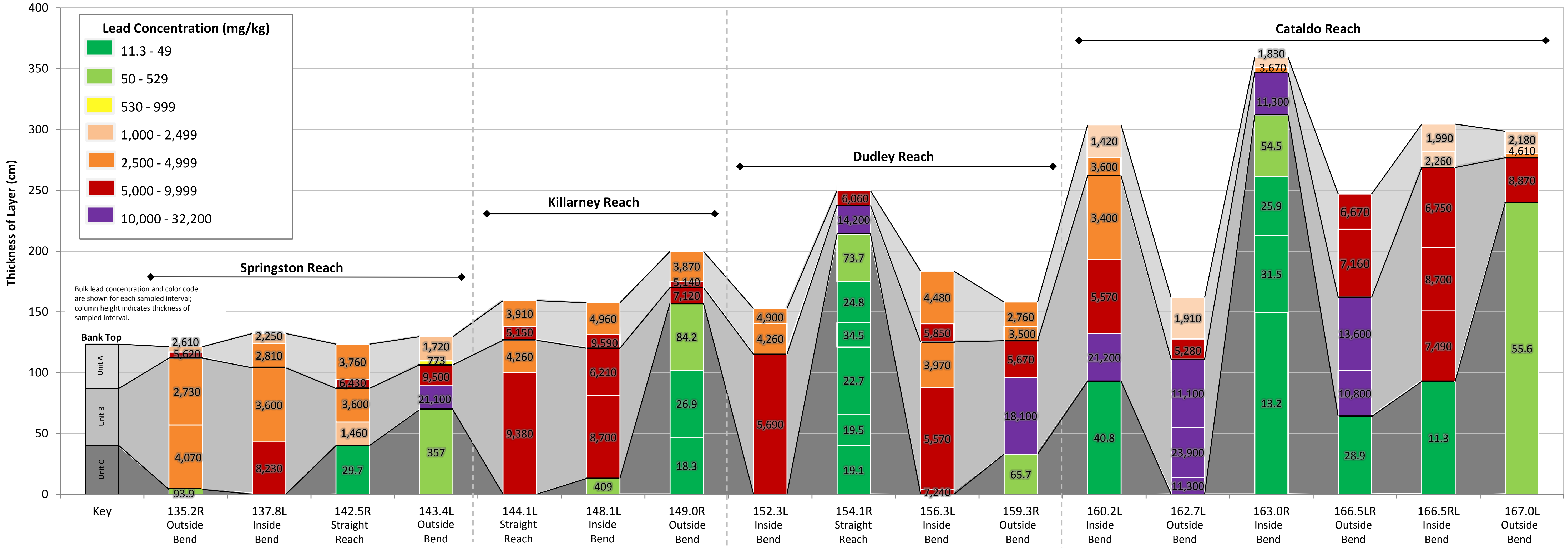


Exhibit 6. **Suspended Sediment Concentration Measurements from USGS and CH2M HILL Sampling Programs**

A. Bulk Lead Concentration (mg/kg) for Bank Face Intervals



B. Total Lead (metric tons) per Stratigraphic Unit (1 m wide and 1 m deep)

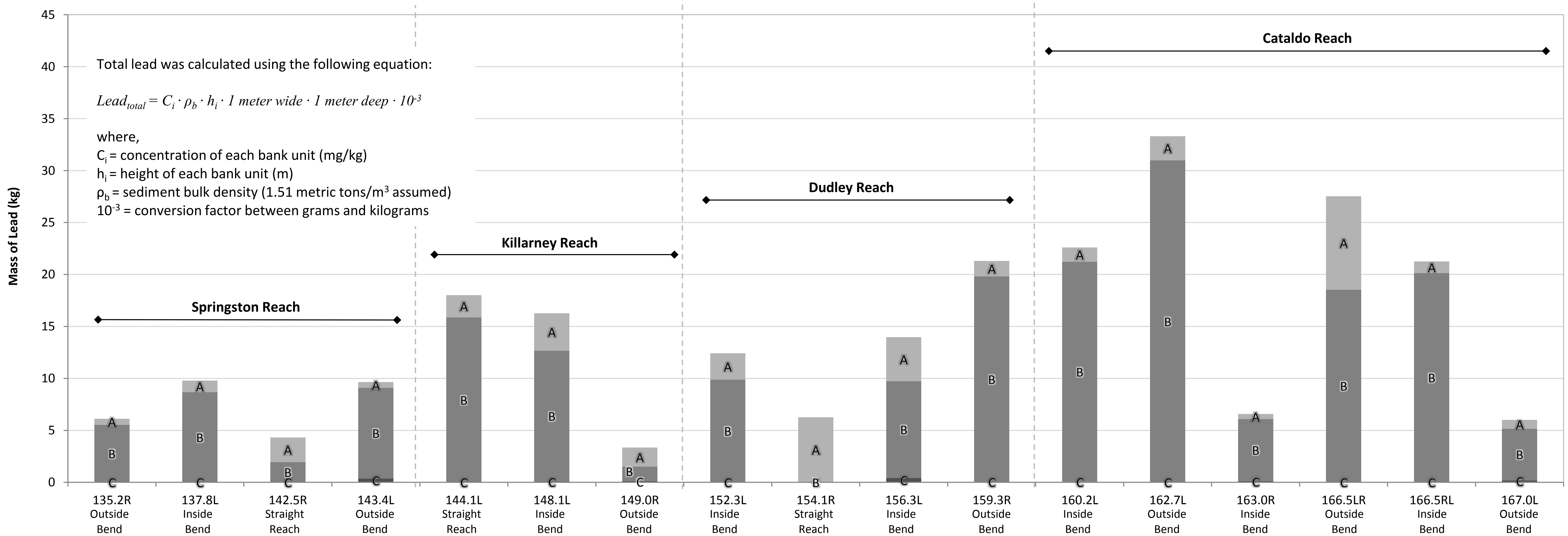


Exhibit 7. **Lead Content and Downstream Pattern of Lead in Riverbanks**

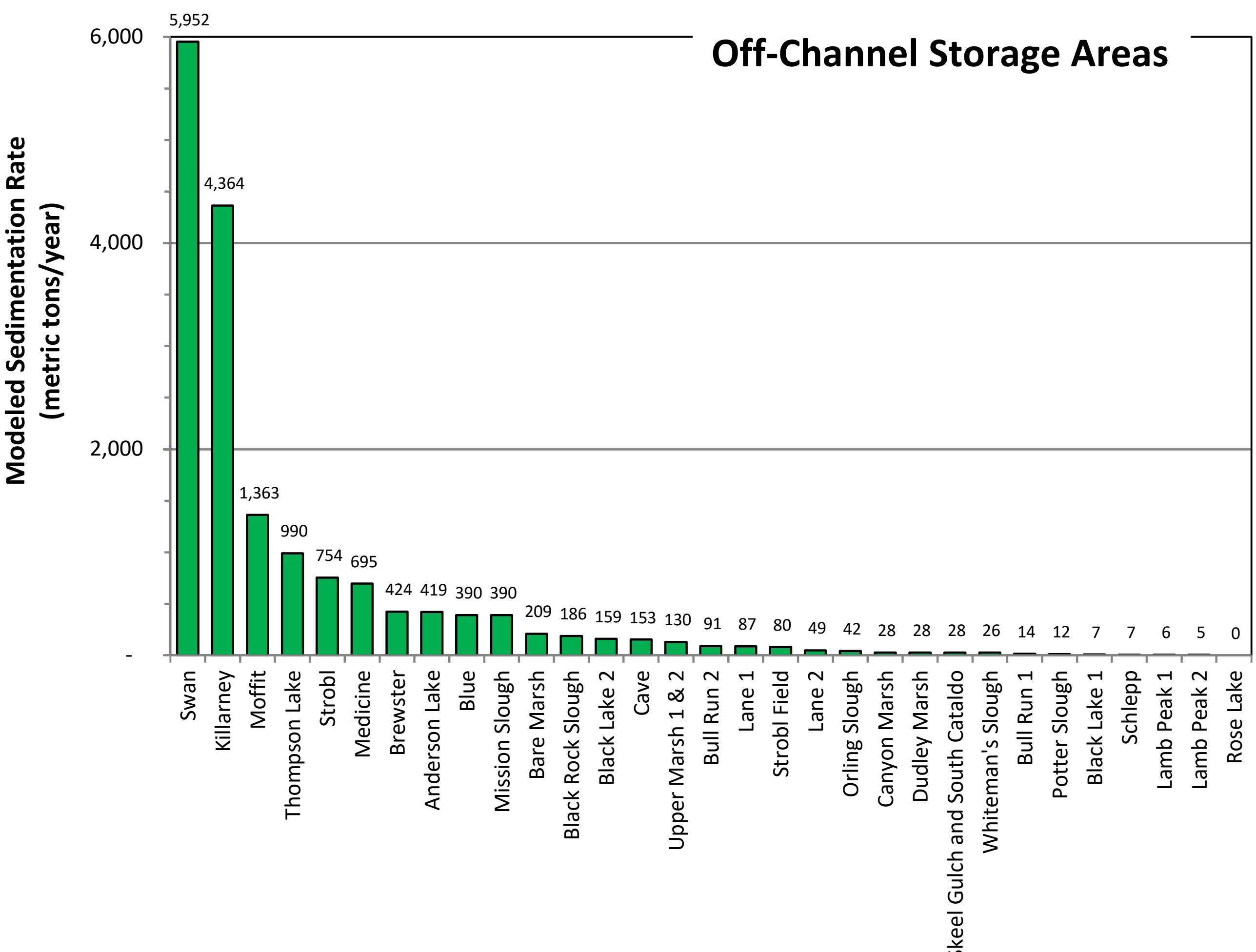
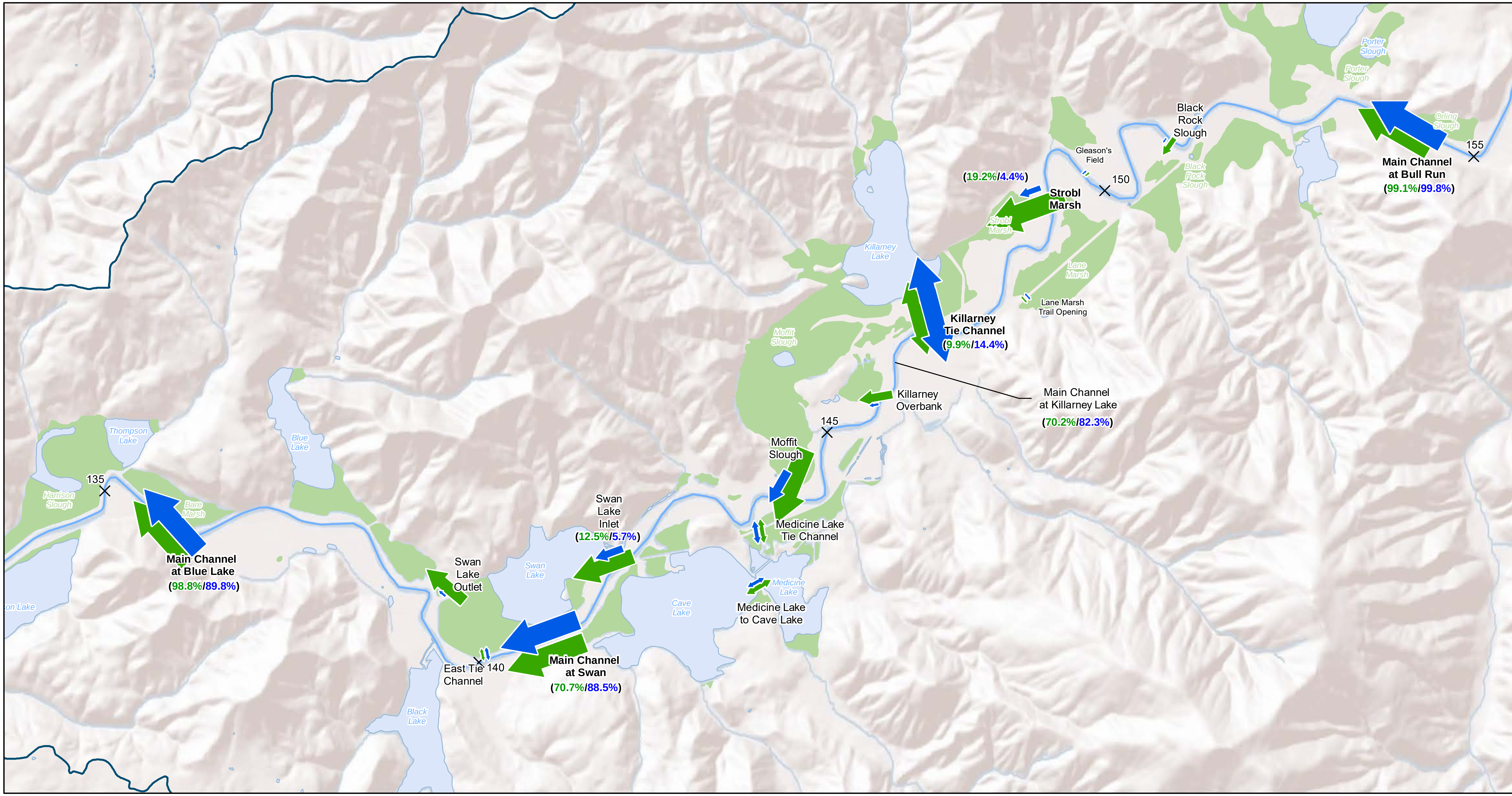
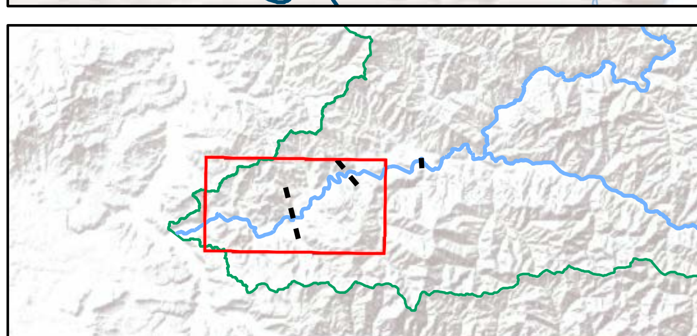


Exhibit 8. **Annual Sediment Deposition in Lower Basin Floodplain**





Legend

Limit to smallest scaled vector

Limit to largest scaled vector

River mile

May 2008 Flow Vector

January 2011 Flow Vector

Flow Direction

0 1,000 2,000 Meters

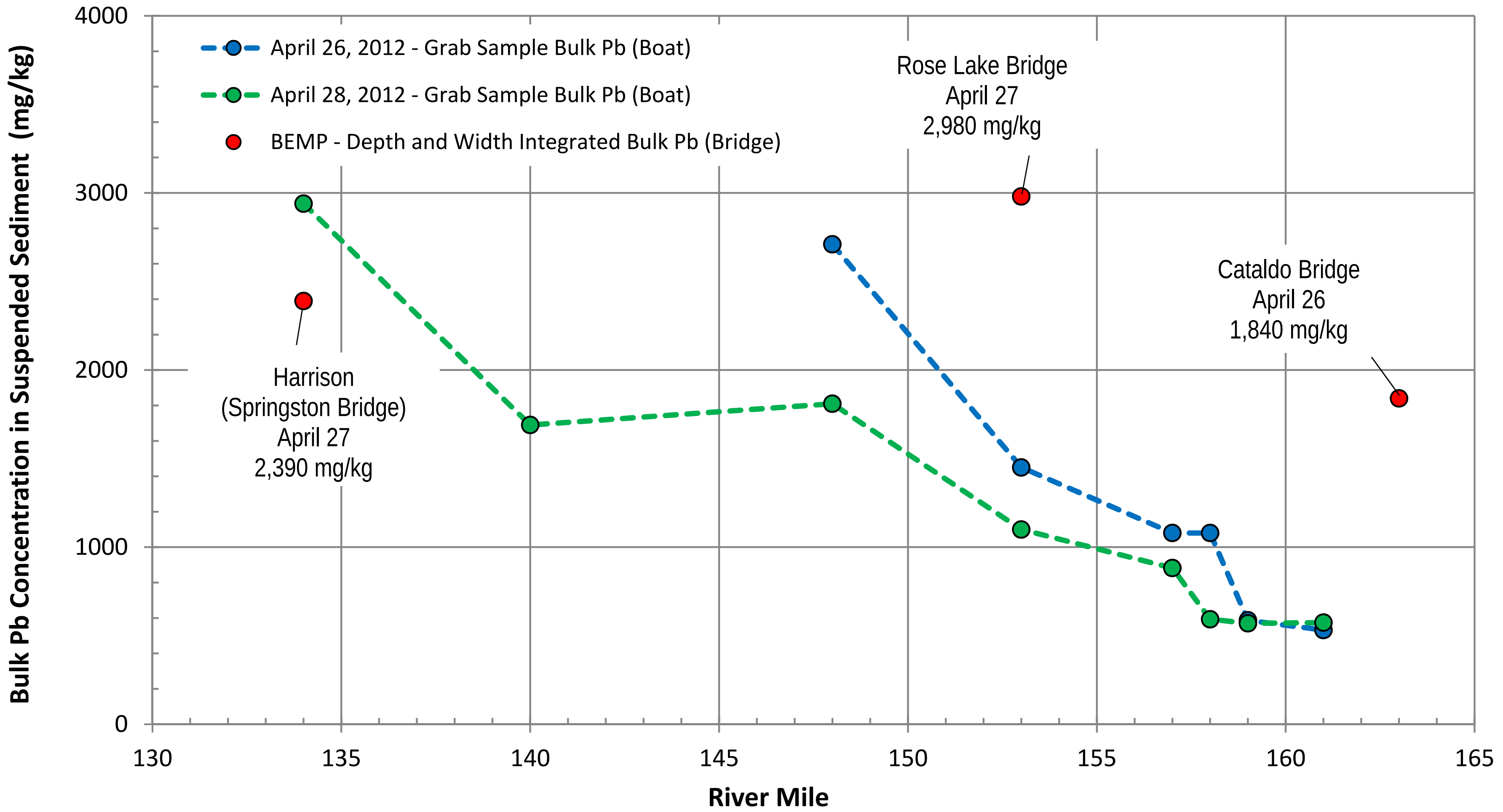
N

Note:
1. Percentages are the percent of total flow volume passing the indicated location relative to volume passing Cataldo, for each event as defined in Exhibit 5 and Section 2.1.1 in TM D-5
2. Size limited arrows are indicated with **bold** text for upper size limit, and smaller font text for lower size limit.

Exhibit 9. **Primary Flow Paths and Tie Channels**
Synopsis
Lower Basin Coeur d'Alene River (OU3)

V:\PR_POSTRIFSSUPPORT\DOCUMENTS\ECSM\SYNOPSIS_OVERVIEW\2019_SYNOPSIS\EXHIBITS\EXHIBIT_9_FLOWPATHS.MXD TB028345 7/15/2019 11:39:26 AM

ch2m



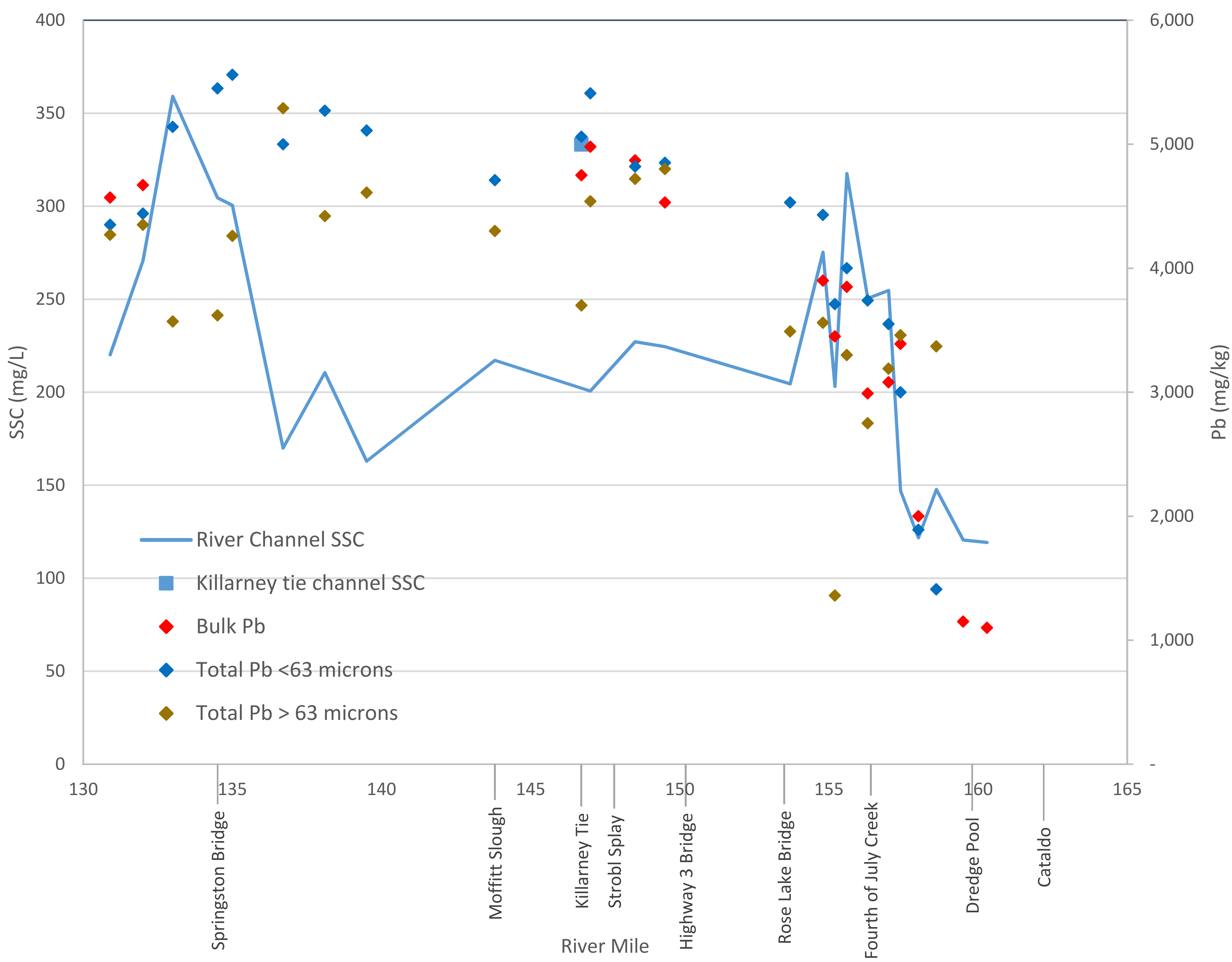


Exhibit 10. **Bulk Pb in Suspended Sediments, April 2012 and March 2017 Flood Events**

Synopsis

Lower Basin Coeur d'Alene River (OU3)

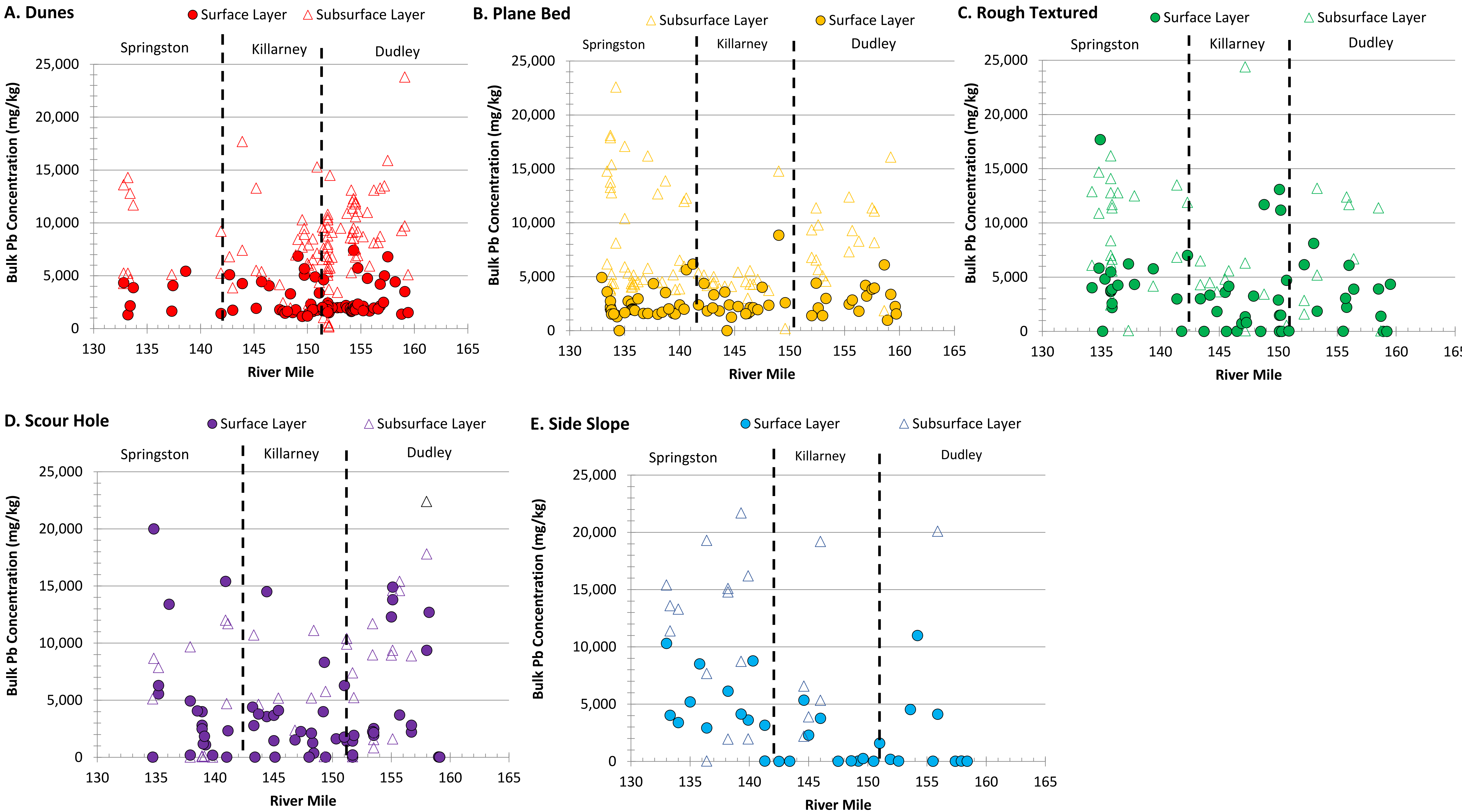
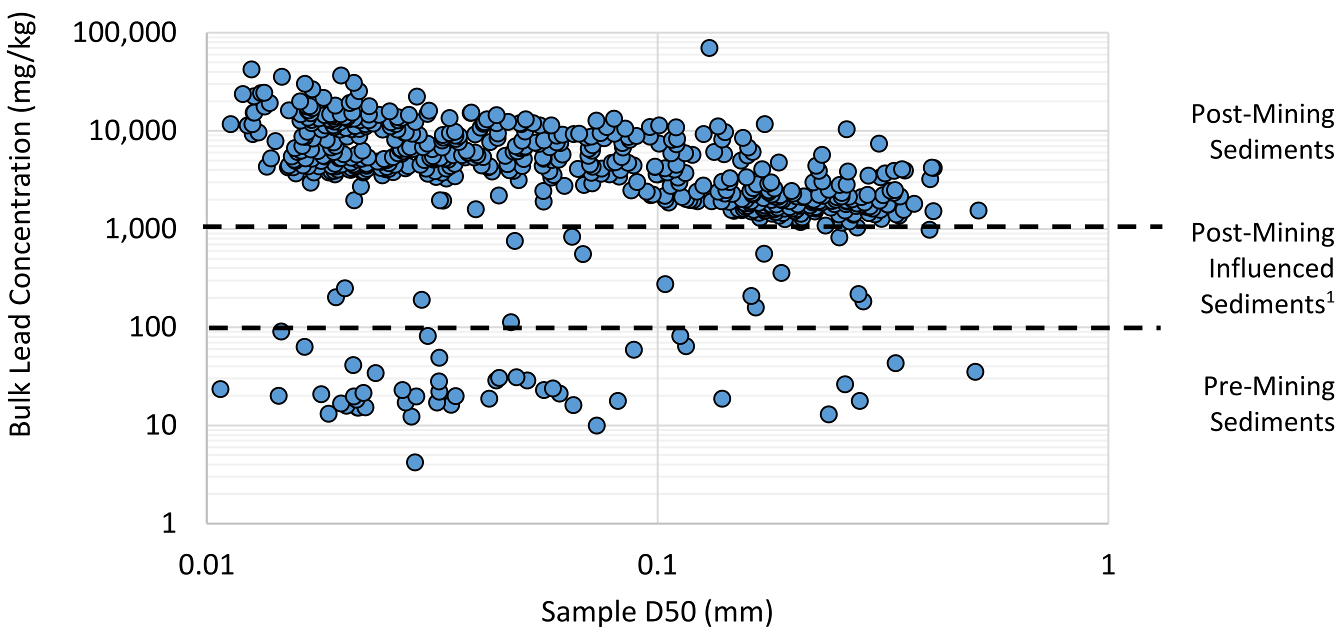


Exhibit 11. **Downstream Pattern in Bulk Lead Concentration in All Riverbed Cores, by Bedform**

Synopsis

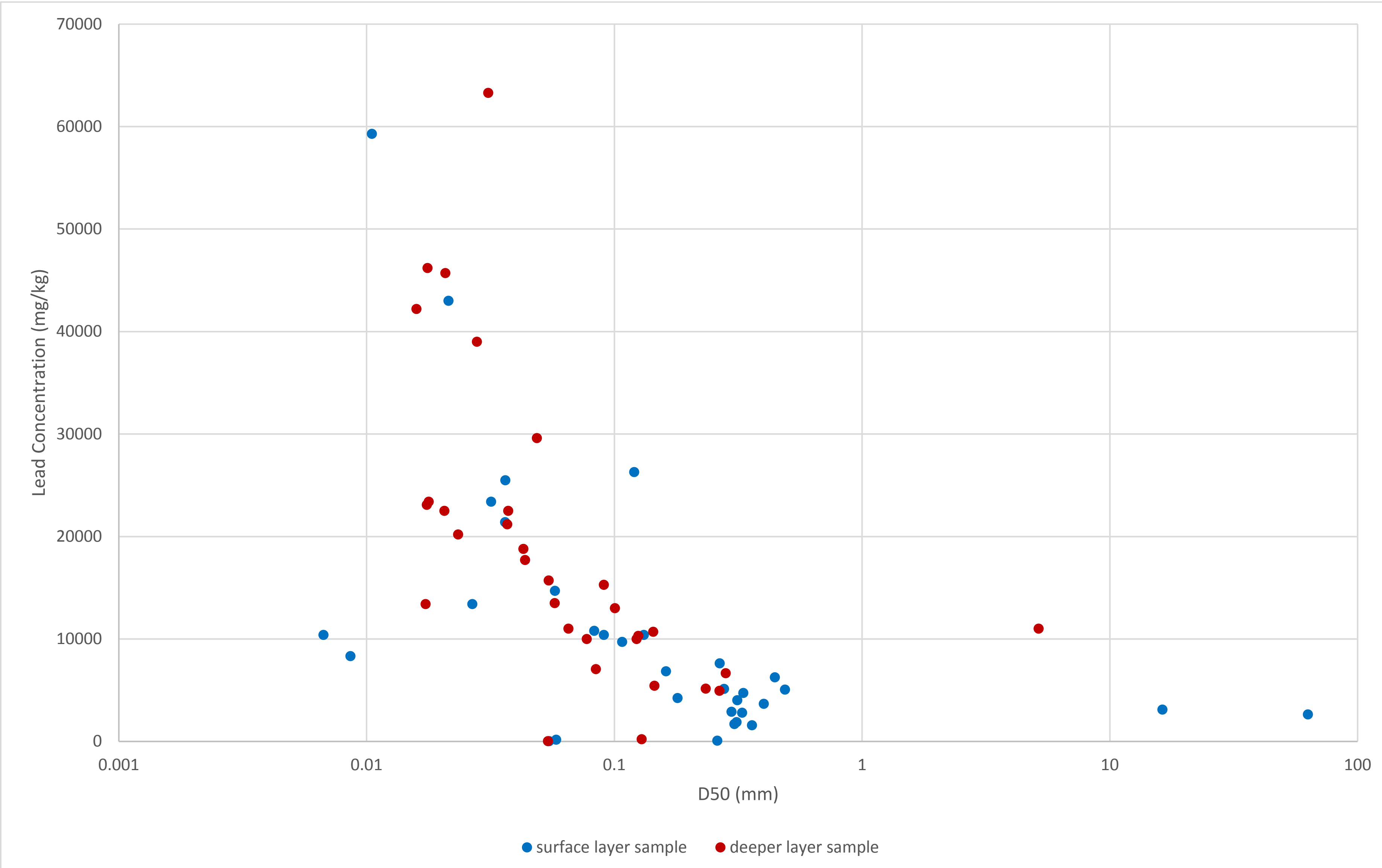
Lower Basin of the Coeur d'Alene River (OU3)

Median Grain Size



Note:
1. The small number of samples with lead concentrations between 100 and 1,000 are interpreted to represent pre-mining sediment that was inadvertently mixed with contaminated sediment during sampling.

Exhibit 12a. **Lead Concentration as a Function of Median Particle Diameter**



Note
Where the sediment and XRF lead concentrations generally were uniform throughout a core, the surface layer was the only sample collected from that core. Other cores were divided into as many as four sample intervals, with up to three deeper layer samples.

Exhibit 12b. **Lead Concentration as a Function of Median Particle Diameter and Percent Fines, 2017 Dudley Reach Riverbed Cores**

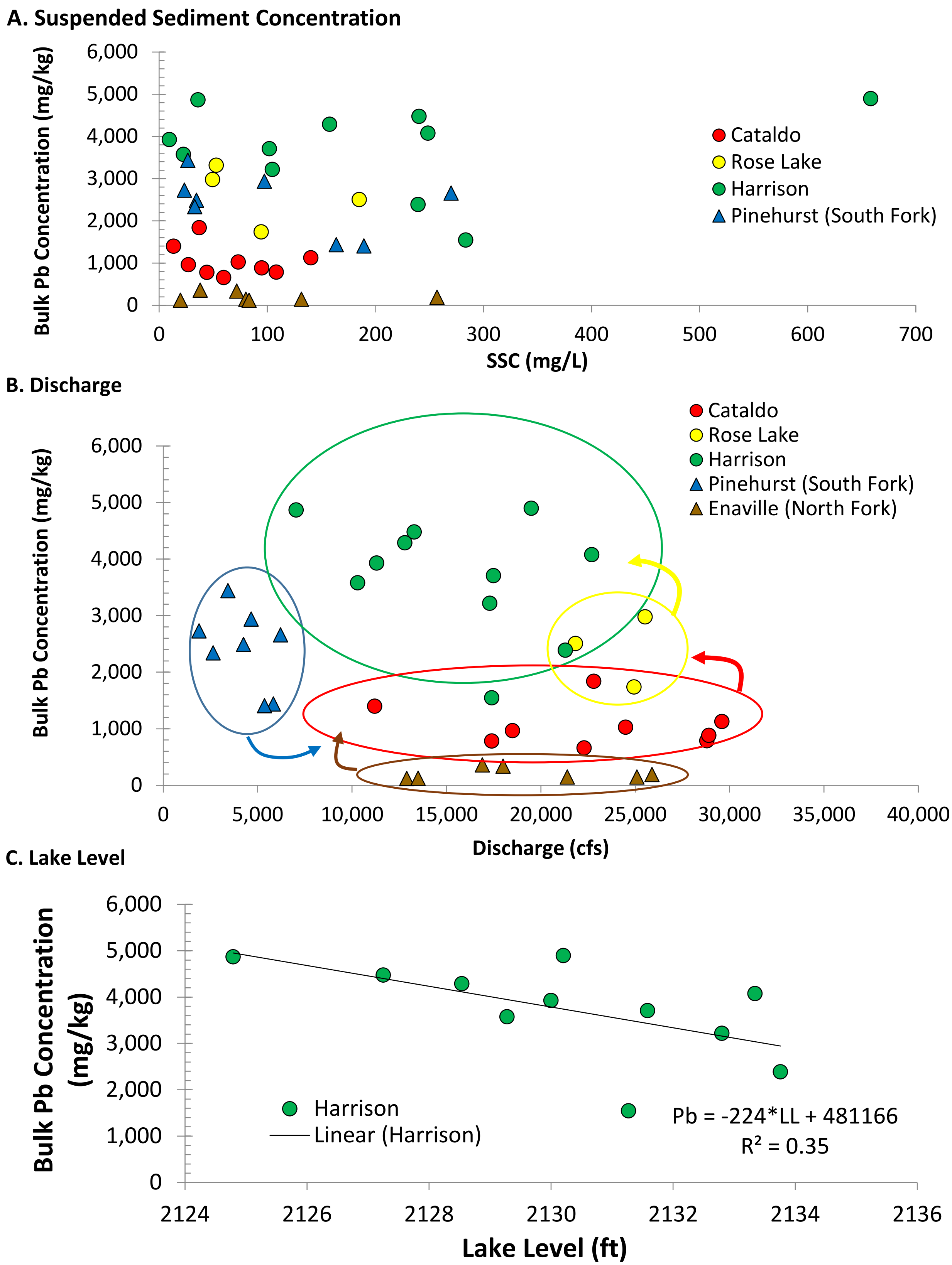
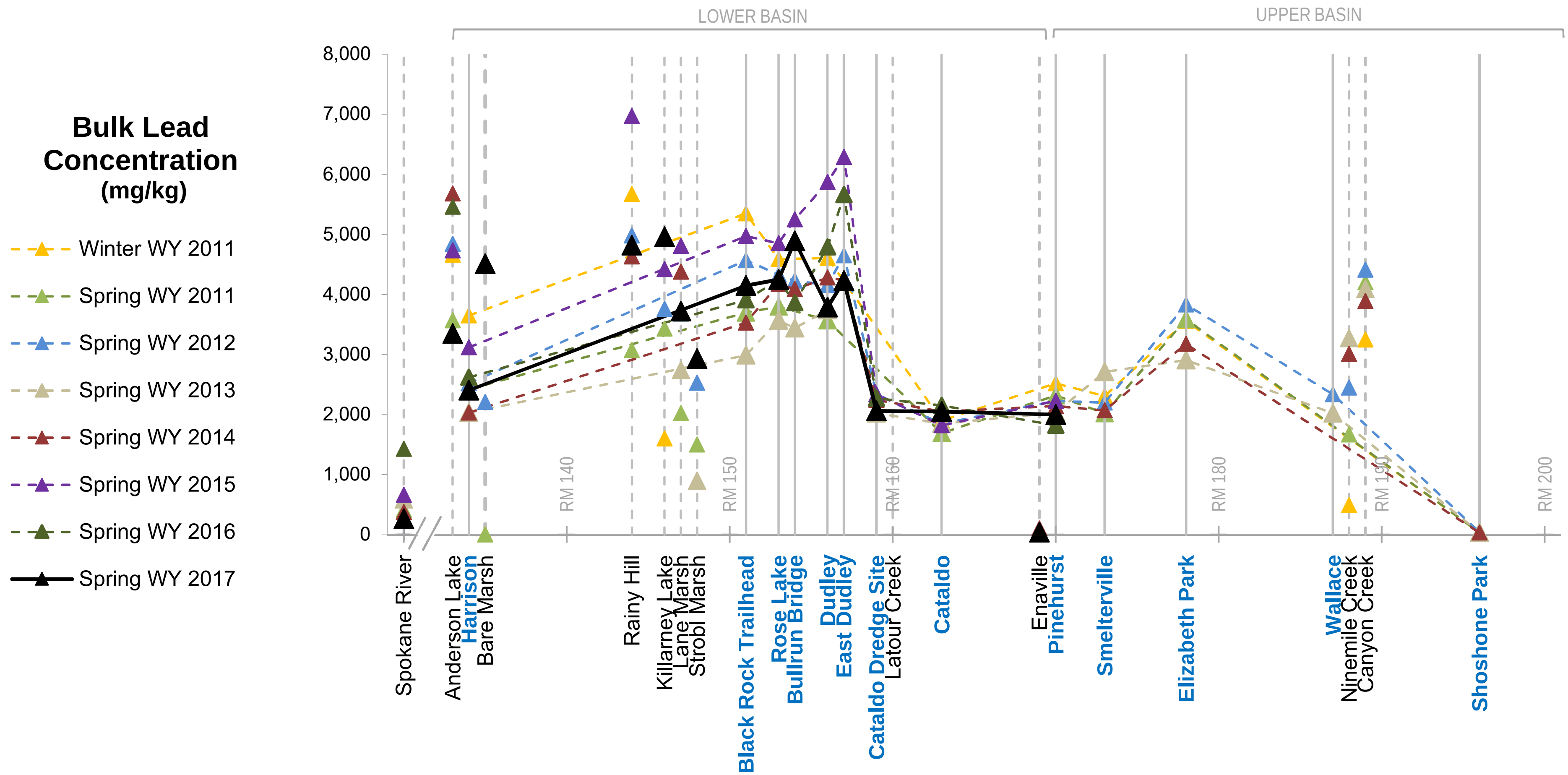
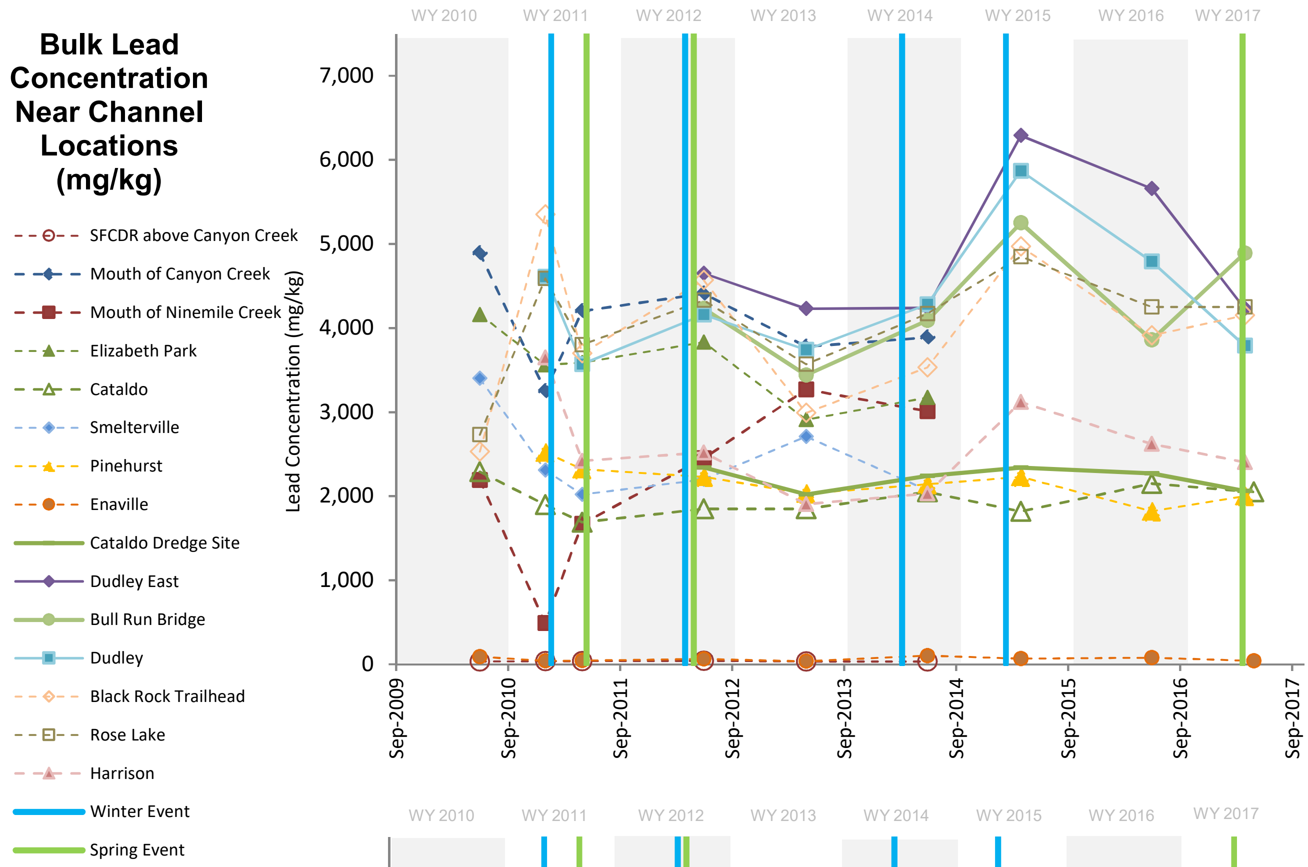


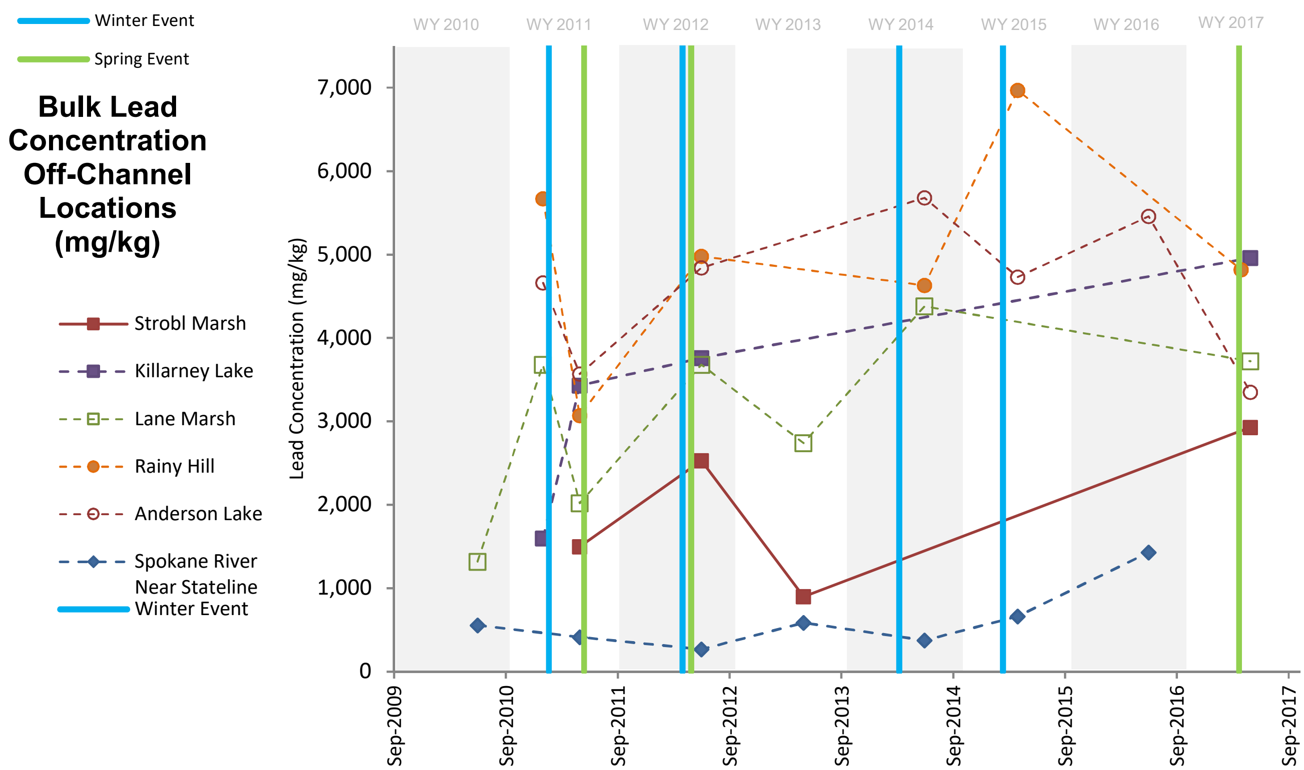
Exhibit 13. **Lead Concentration on Suspended Sediment**



Notes:
Metal concentration for bulk samples based on analysis of particles ≤4.75 mm in size. Sampling stations along the South Fork and the Mainstem are shown as connected points, while sampling stations on tributaries and off-channel floodplains are shown as unconnected points.
Bold = Mainstem and South Fork locations

Exhibit 14. **WY 2011 through WY 2017 Lead Concentration in BEMP Depositional Samples**



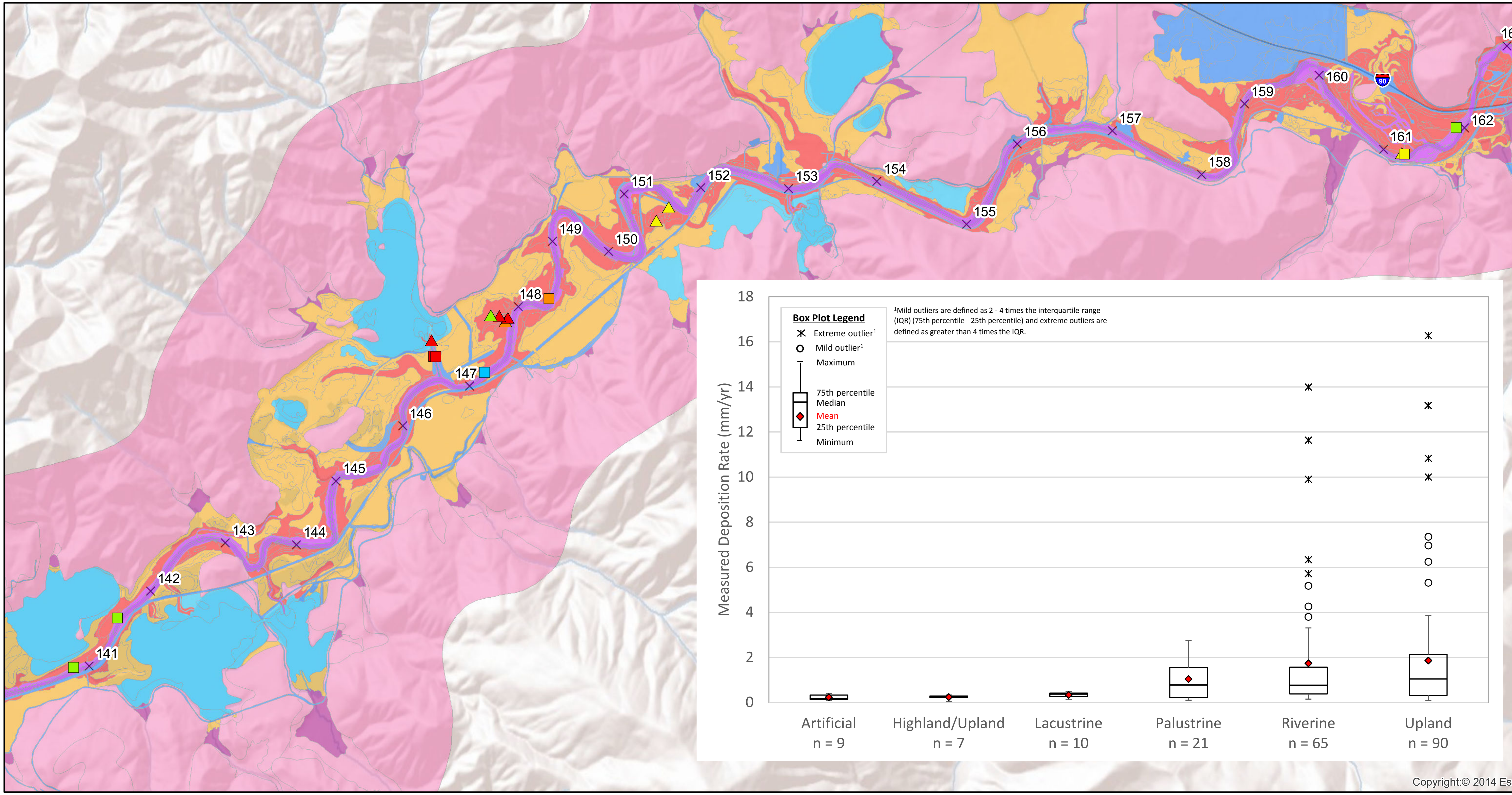


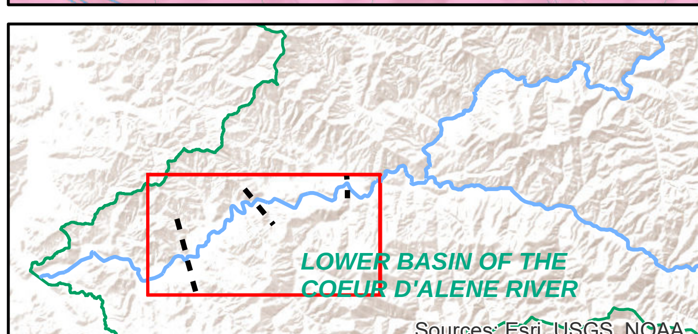
Notes:
Metal concentration for bulk samples based on analysis of particles ≤4.75 mm in size.
Data shown for depositional sampling stations sampled in WY2010 through WY2017.
Data for stations sampled more than once per event were averaged for display.

Exhibit 15. **Bulk Lead Concentrations in BEMP Depositional Samples Over Time**

Synopsis

Lower Basin Coeur d'Alene River (OU3)





LEGEND

Measured Deposition Rate

Annualized deposition rate using the MSH layer as time marker; Upland symbolized by triangles and Riverine symbolized by squares

- <4 mm/yr
- 4 - 6 mm/yr
- 6 - 8 mm/yr
- 8 - 10 mm/yr
- >10 mm/yr

Wetland Type (Bookstrom, 1999)

- Artificial
- Highland
- Highland/Upland
- Lacustrine
- Palustrine
- Riverine
- Upland

× Rivermile

0 0.5 1 2 Miles

N

Flow Direction

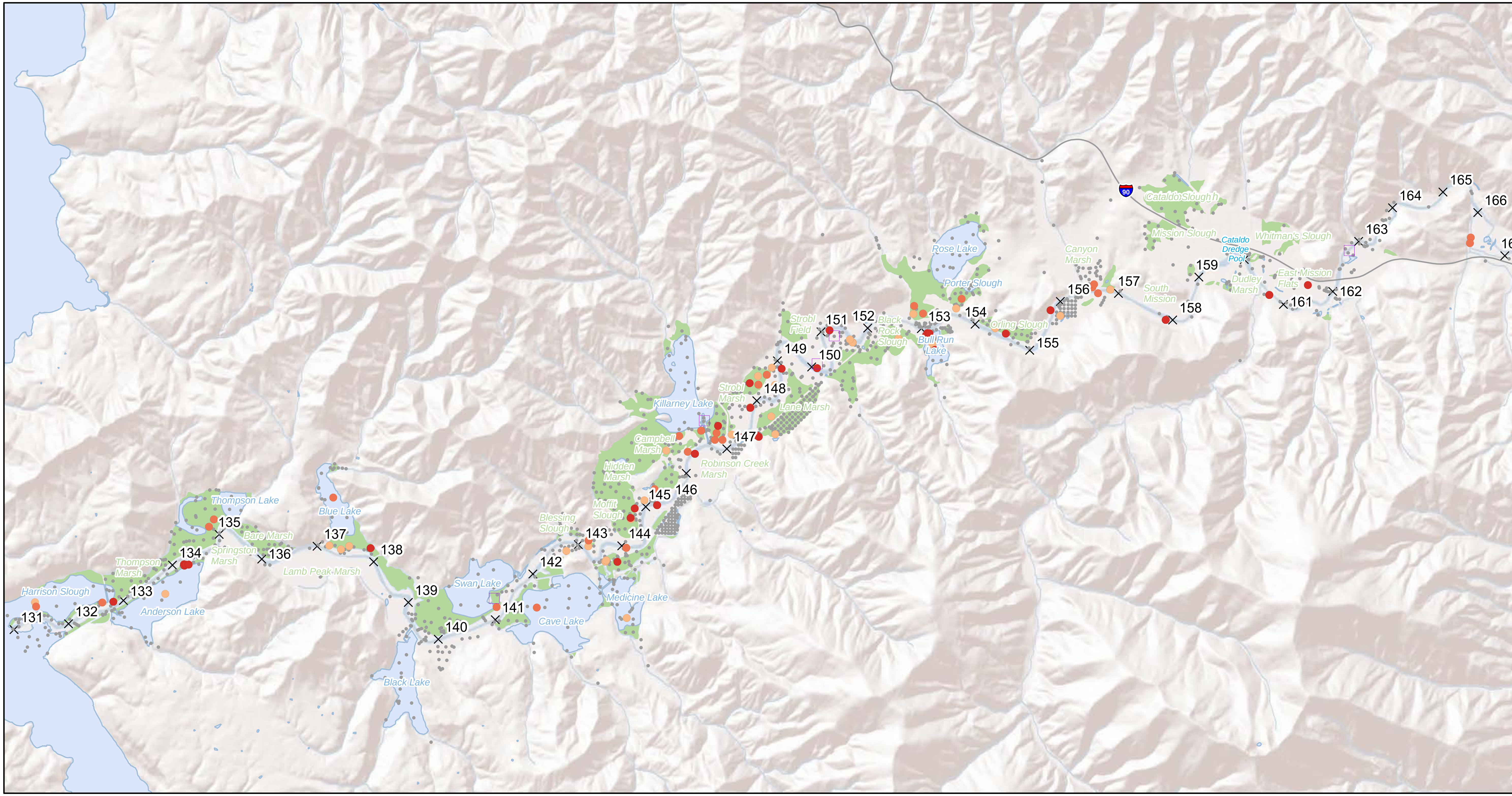
Exhibit 16. **Floodplain Landforms and Box Plots of Measured Floodplain Depositional Rates by Landform Type**

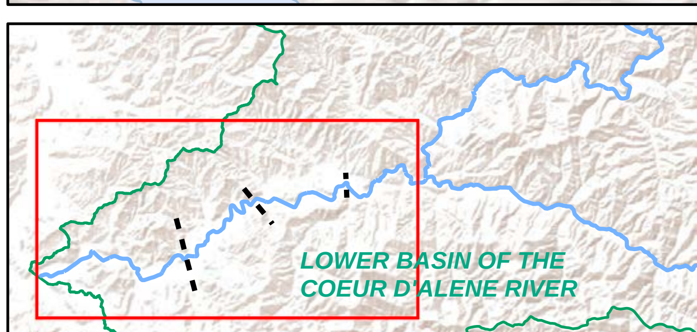
Synopsis

Lower Basin of the Coeur d'Alene River (OU3)

ch2m

\\PDXFPP01\PROJ\USEPA\676513BUNKERHILL\GIS\MAPFILES\2018\TM E-8\EXHIBIT_24_BOXPLOTOUTLIERLOCATIONS.MXD GGEE 8/3/2018 9:05:59 AM





LEGEND

Lead Concentration "Hot Spot" Analysis Results[1]

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- Not Significant
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence
- Recreation Site
- Rivermile
- Waterbody
- Marsh or Slough

Note:
[1]A hot spot is a statistically significant spatial clustering of high values.
A cold spot is a statistically significant spatial clustering of low values.

0 3,750 7,500 15,000 Feet

N

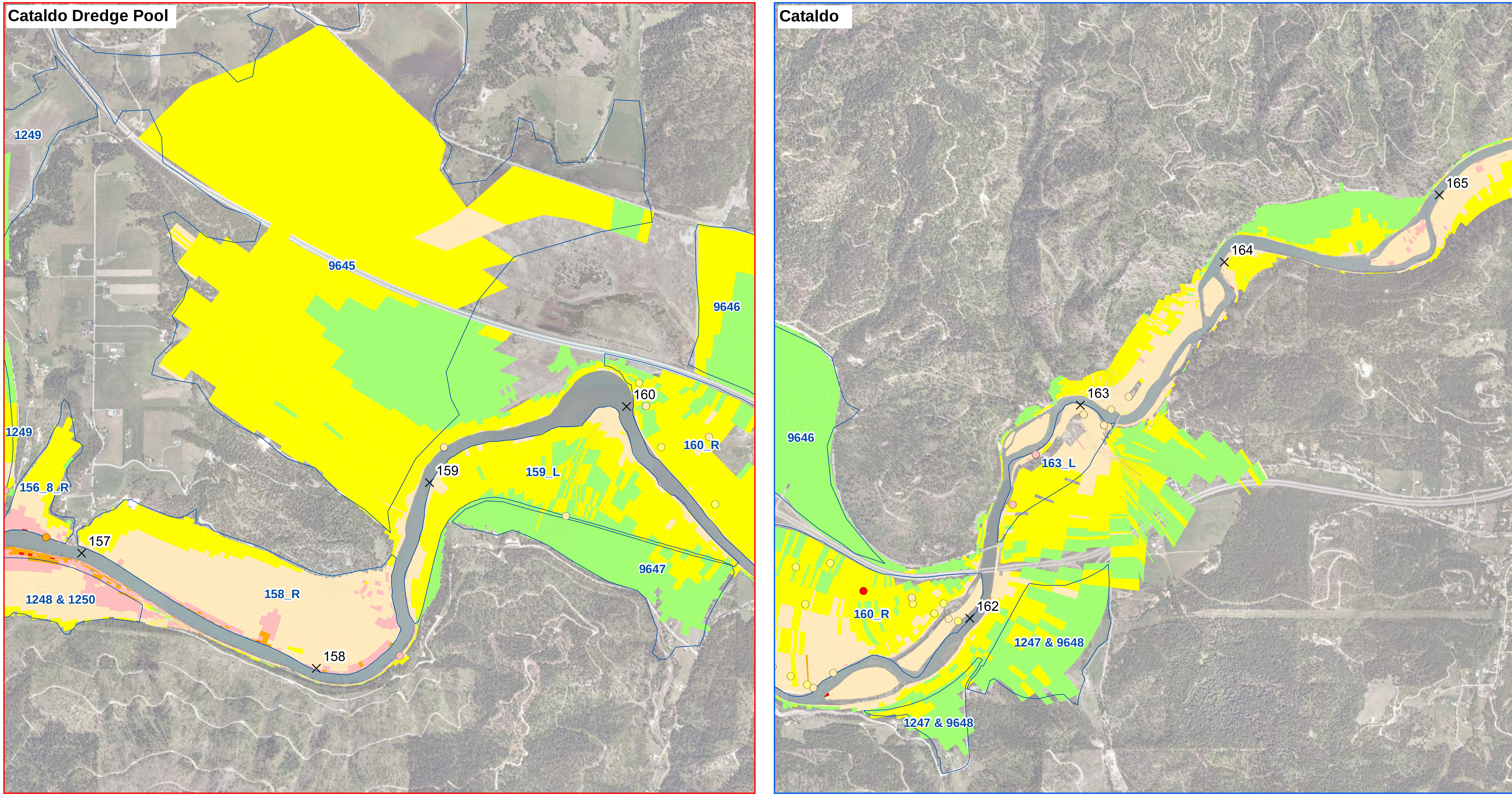
Flow Direction

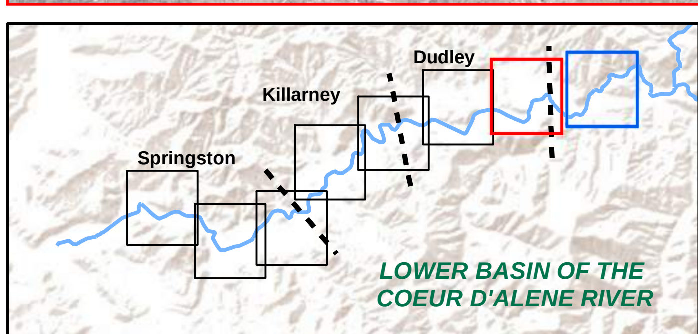
Exhibit 17. **Hot Spots of Surface Samples**

Synopsis

Lower Basin Coeur d'Alene River (OU3)

ch2m:





Surface Lead Concentration (mg/kg)*

- < 100
- 100 - 529
- 530 - 999
- 1,000 - 2,499
- 2,500 - 4,999
- 5,000 - 9,999
- 10,000 - 19,999
- 20,000 - 39,999
- > 40,000

Note:
*This scale applies to both the STM predictions and the observations.

Sample Years Shown
2007, n= 97
2008, n= 93
2015, n= 33
2016, n= 174

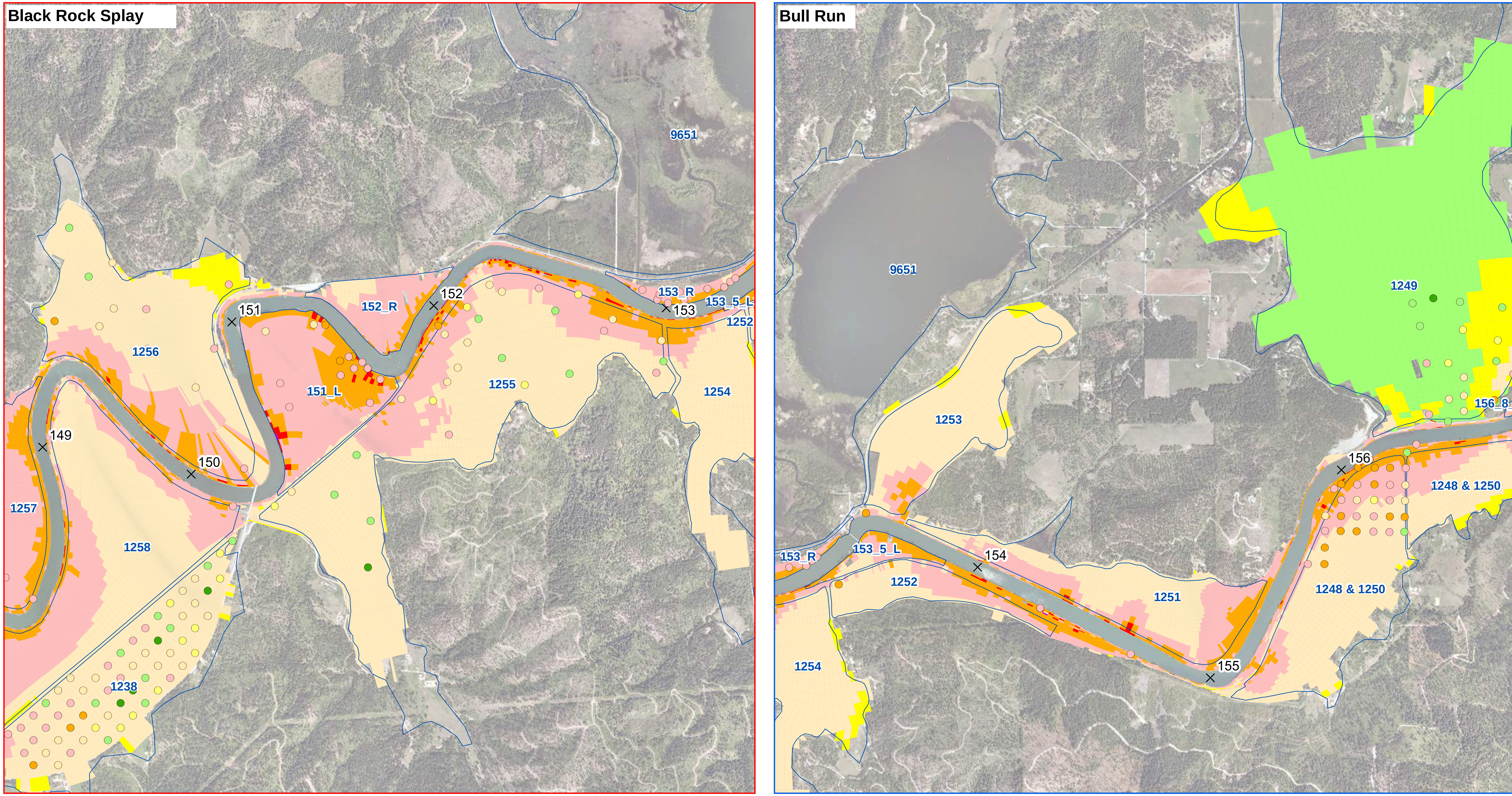
0 500 1,000 Meters

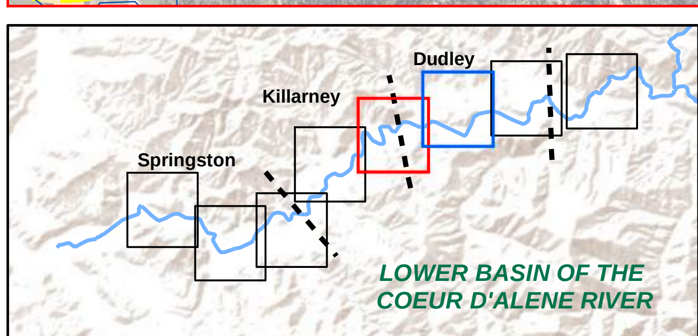
N

Flow Direction

Figure 18. **Floodplain Surface Lead Concentration STM and Floodplain Samples, Filtered by Year**
Synopsis
Lower Basin Coeur d'Alene River (OU3)

ch2m





Surface Lead Concentration (mg/kg)*

- < 100
- 100 - 529
- 530 - 999
- 1,000 - 2,499
- 2,500 - 4,999
- 5,000 - 9,999
- 10,000 - 19,999
- 20,000 - 39,999
- > 40,000

Note:
*This scale applies to both the STM predictions and the observations.

Sample Years Shown
2007, n= 97
2008, n= 93
2015, n= 33
2016, n= 174

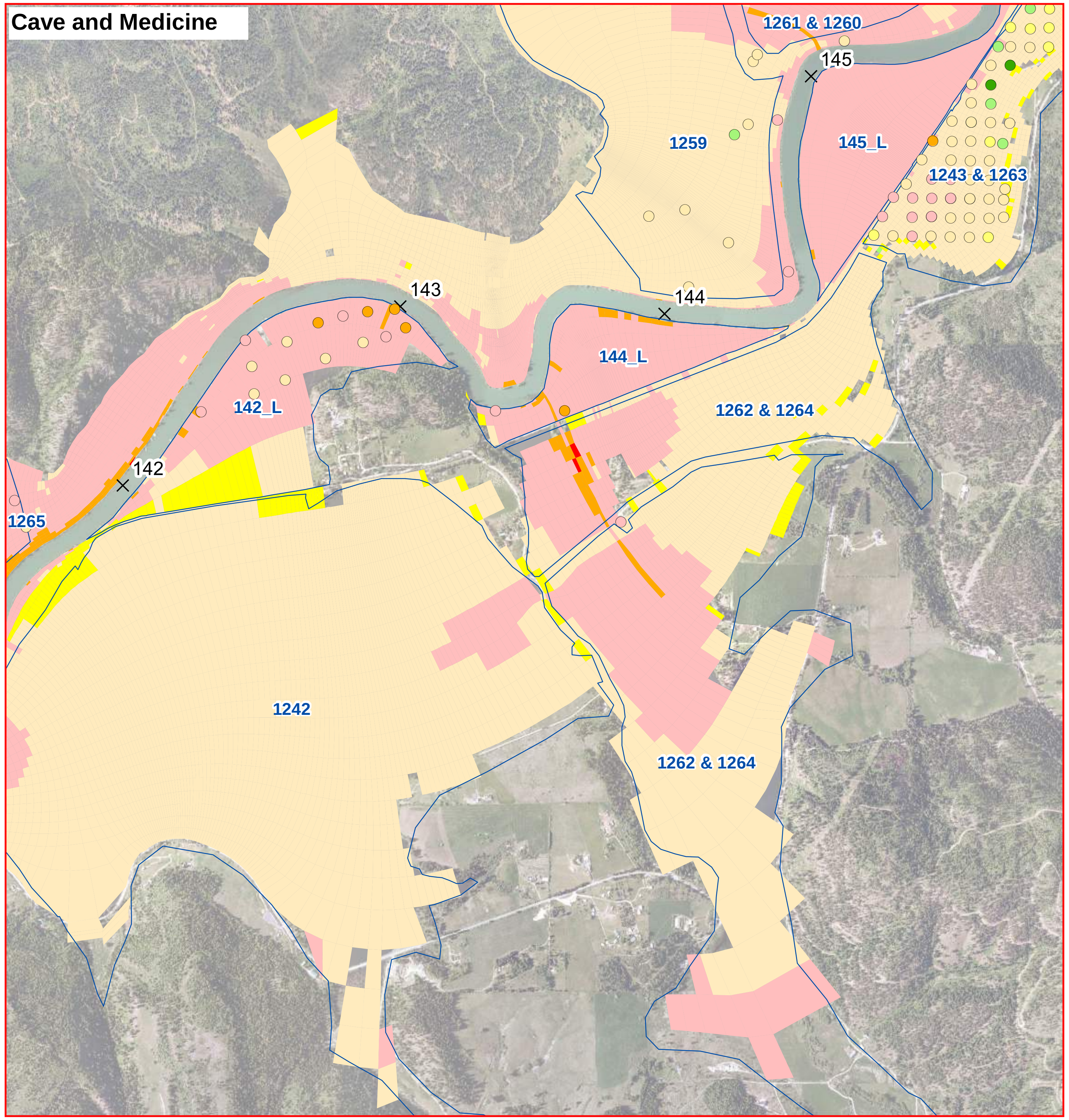
0 500 1,000 Meters

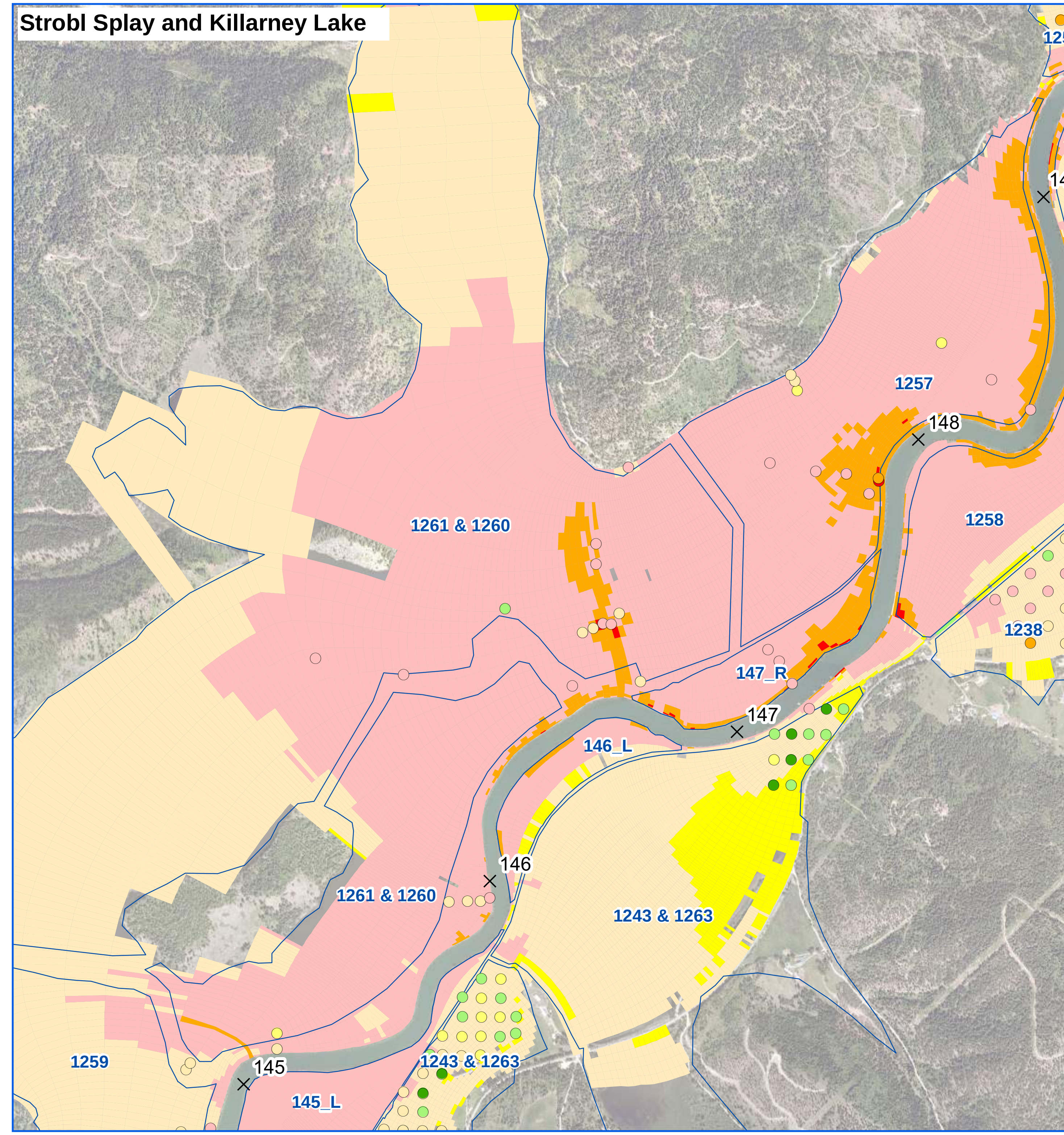
N

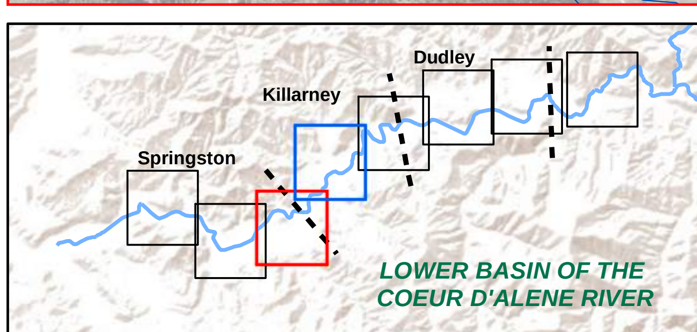
Flow Direction

Figure 18. **Floodplain Surface Lead Concentration STM and Floodplain Samples, Filtered by Year**
Synopsis
Lower Basin Coeur d'Alene River (OU3)

ch2m







Surface Lead Concentration (mg/kg)*

< 100	2,500 - 4,999
100 - 529	5,000 - 9,999
530 - 999	10,000 - 19,999
1,000 - 2,499	20,000 - 39,999
	> 40,000

Note:
*This scale applies to both the STM predictions and the observations.

Sample Years Shown
2007, n= 97
2008, n= 93
2015, n= 33
2016, n= 174

0 500 1,000 Meters

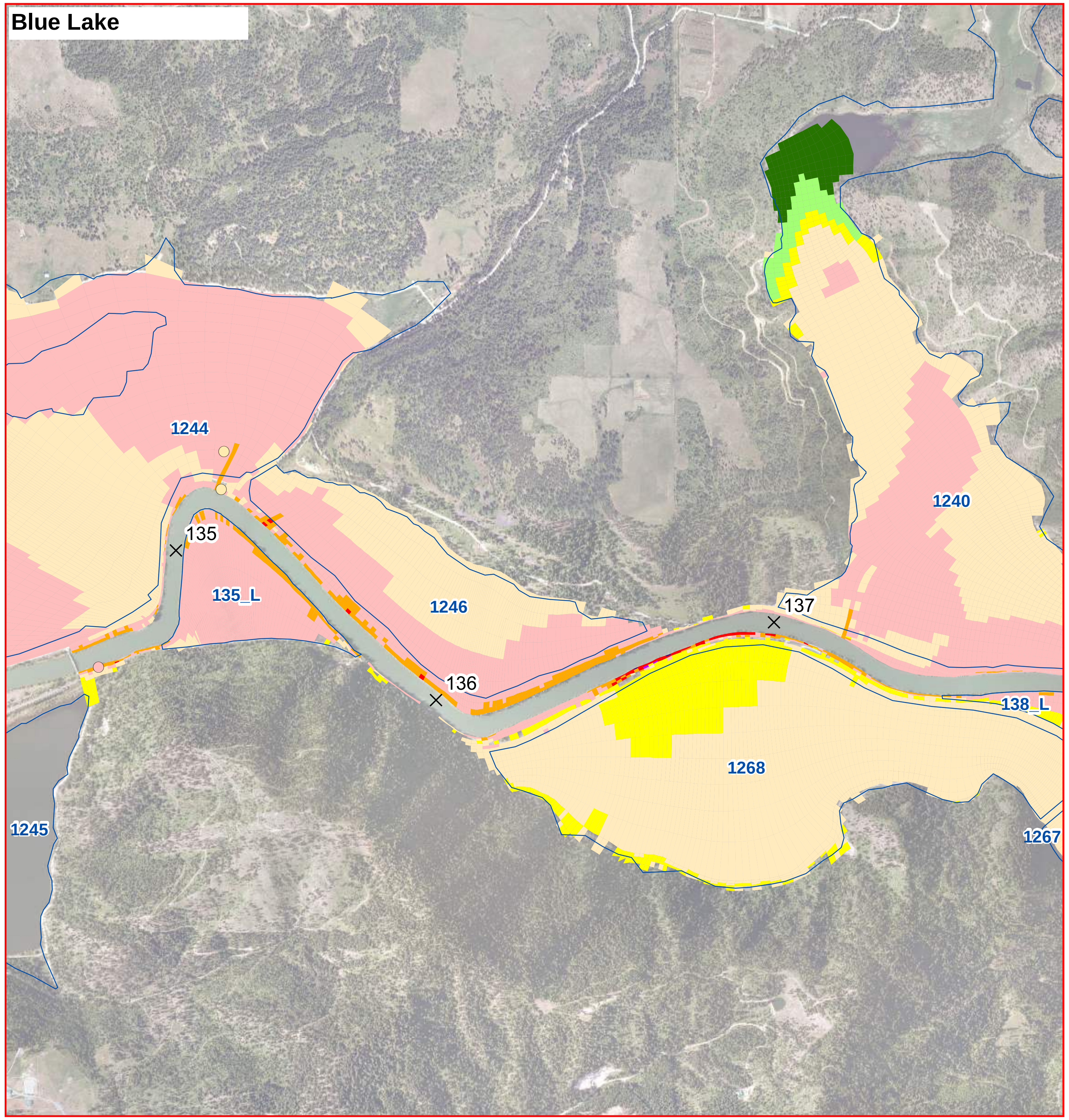
N

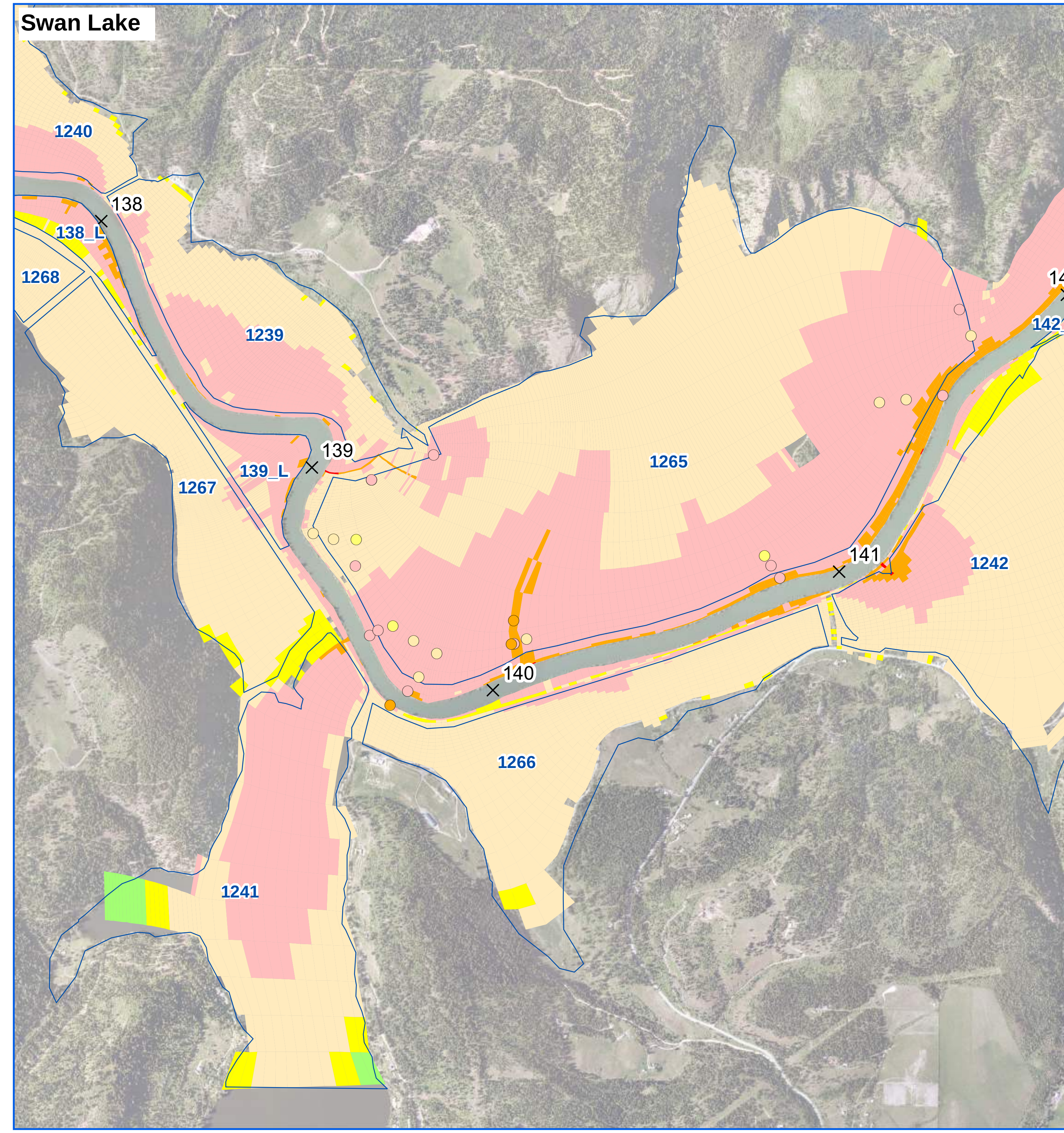
Flow Direction

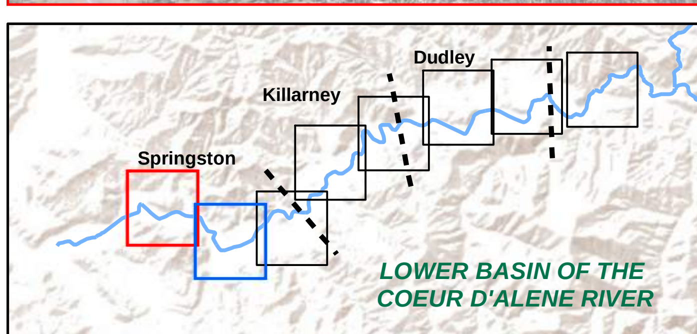
Exhibit 18. **Floodplain Surface Lead Concentration**
STM and Floodplain Samples, Filtered by Year
Synopsis
Lower Basin Coeur d'Alene River (OU3)

D:\CH2M-PROJECTS\676513CH_CDA\PYTHON\LTNA_ALLFLOODPLAINCORES_YEARFILTERED\LTNA_ALLFLOODPLAINCORES_FILTEREDBYYEAR.MXD TB028345 7/15/2019 10:23:45 PM

ch2m







Surface Lead Concentration (mg/kg)*

- < 100
- 100 - 529
- 530 - 999
- 1,000 - 2,499
- 2,500 - 4,999
- 5,000 - 9,999
- 10,000 - 19,999
- 20,000 - 39,999
- > 40,000

Note:
*This scale applies to both the STM predictions and the observations.

Sample Years Shown
2007, n= 97
2008, n= 93
2015, n= 33
2016, n= 174

0 500 1,000 Meters

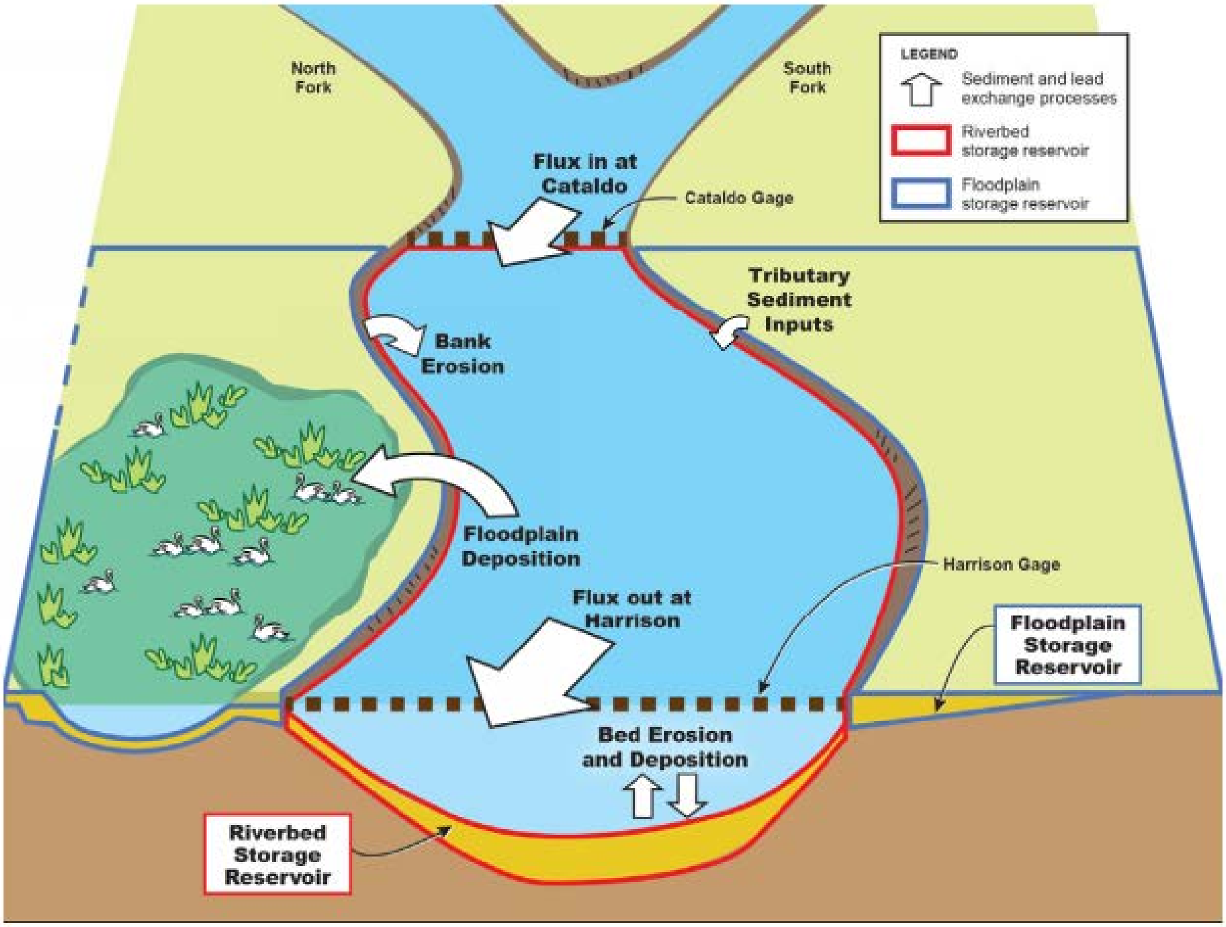
N

Exhibit 18. **Floodplain Surface Lead Concentration STM and Floodplain Samples, Filtered by Year**
Synopsis
Lower Basin Coeur d'Alene River (OU3)

Flow Direction

D:\CH2M-PROJECTS\676513CH_CDA\PYTHON\LTNA_ALLFLOODPLAINCORES_YEARFILTERED\LTNA_ALLFLOODPLAINCORES_FILTEREDBYYEAR.MXD TB028345 7/15/2019 10:23:45 PM

ch2m:



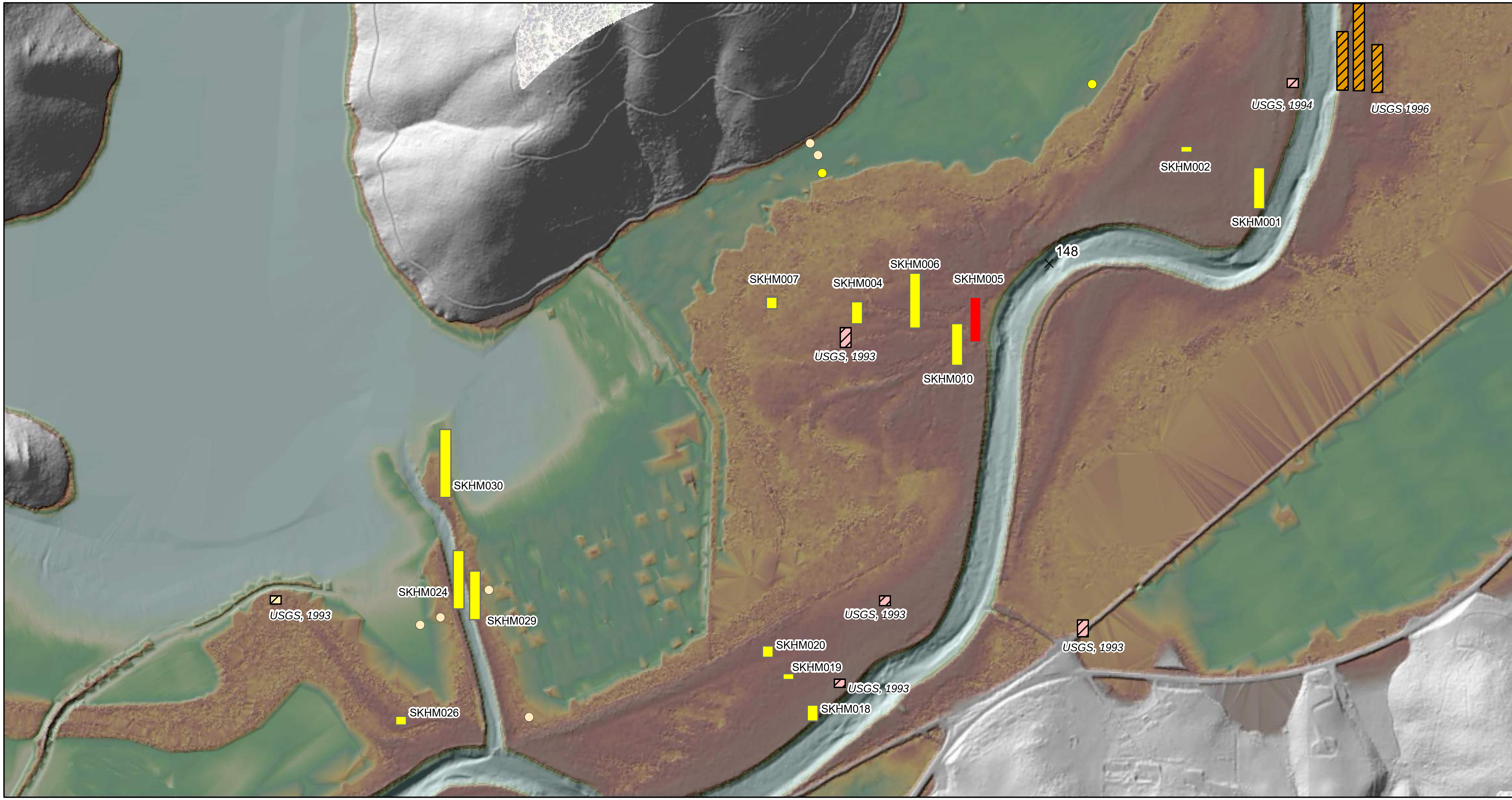
Note:
Tributary sediment inputs are assumed to be small compared with the other components of the sediment budget. No data or analyses were done to try to constrain tributary sediment inputs.

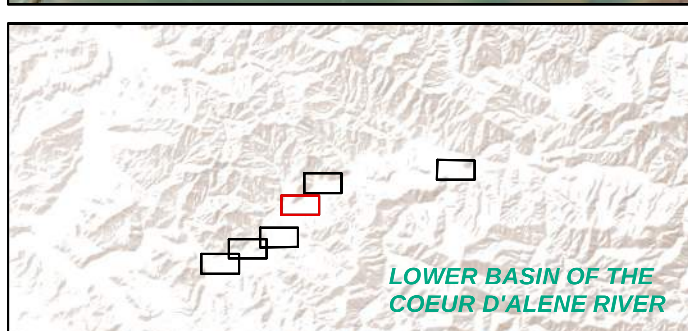
Sediment and Lead Budgets for the Lower Basin (Cataldo to Harrison Gages)

	Mass of Contaminated Sediment Transfer (metric tons/yr)[1]	Mass Lead Transfer (metric tons/yr)[1]	Average STM-Estimated Mass of Contaminated Sediment Transfer (metric tons/yr)[2]	Average STM-Estimated Mass Lead Transfer (metric tons/yr)[2]
Sediment and Lead Sources				
Bed Erosion Rate	35,000	180	34,000	200
Flux in at Cataldo	32,000	34	41,000	30
Bank Erosion	4,900	32	NA	NA
Sediment and Lead Sinks				
Flux out at Harrison	48,000	180	46,000	150
Floodplain Deposition	24,000	68	29,000	80

Notes
All values rounded to two significant digits unless otherwise noted.
1. Values refer to the amount of sediment or lead contributed to loading on average between the Cataldo and Harrison gaging stations, as estimated in ECSM TM D-3.
2. Values refer to the amount of sediment or lead contributed to loading on average between the Cataldo and Harrison gaging stations, as estimated by the STM.

Exhibit 19. **Conceptual Model of Sediment and Lead Budgets from Observed Data and the STM**





Deposition Rate (mm/yr):

15 cm
7.5 cm
0 cm

XRF Measured Lead (mg/kg)

- < 100
- 100 to 529
- 530 to 999
- 1,000 to 2,499
- 2,500 to 4,999
- 5,000 to 9,999
- 10,000 to 19,999
- 20,000 to 39,999
- > 40,000

USGS Samples from the 1990s

Samples without Ash Layer Present
(Fill color represents surface lead concentration)

Notes:
1. USGS samples from the 1990s do not provide a direct comparison with 2016 floodplain samples due to different time intervals between sampling programs.
2. 70 of the 114 samples have field identified Ash Layer
3. Deposition rate calculated as depth to ash layer divided by years since 05/18/1980 (Mt. St. Helens Eruption).

Flow Direction

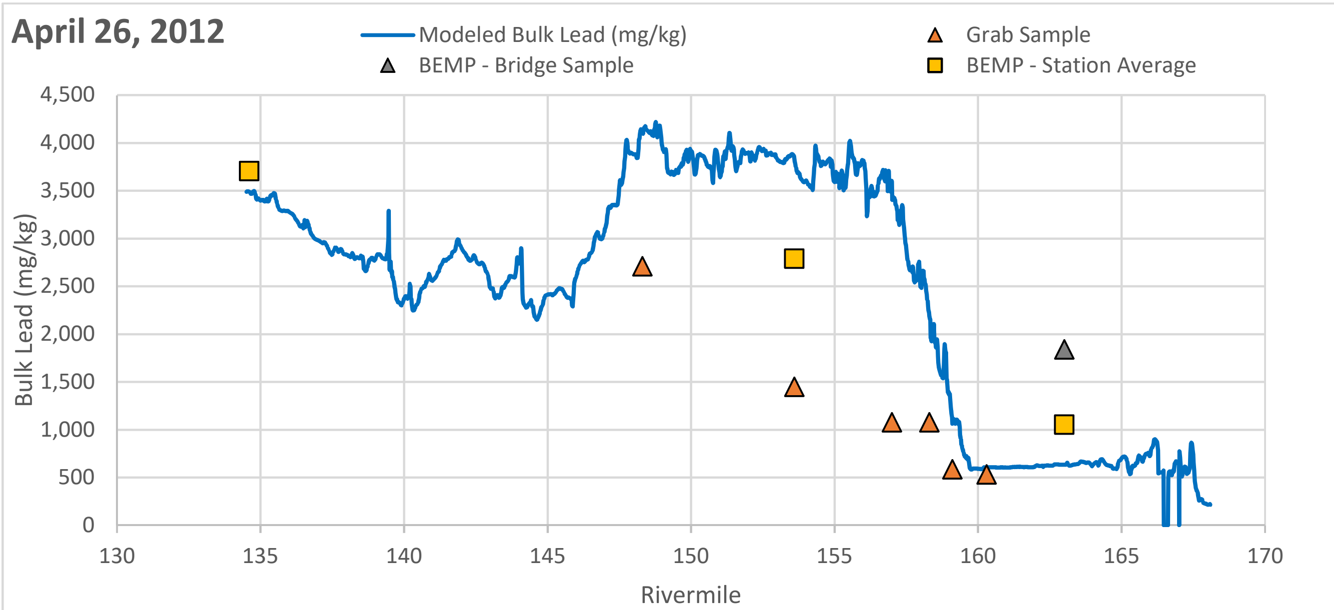
0 100 200 400
Meters

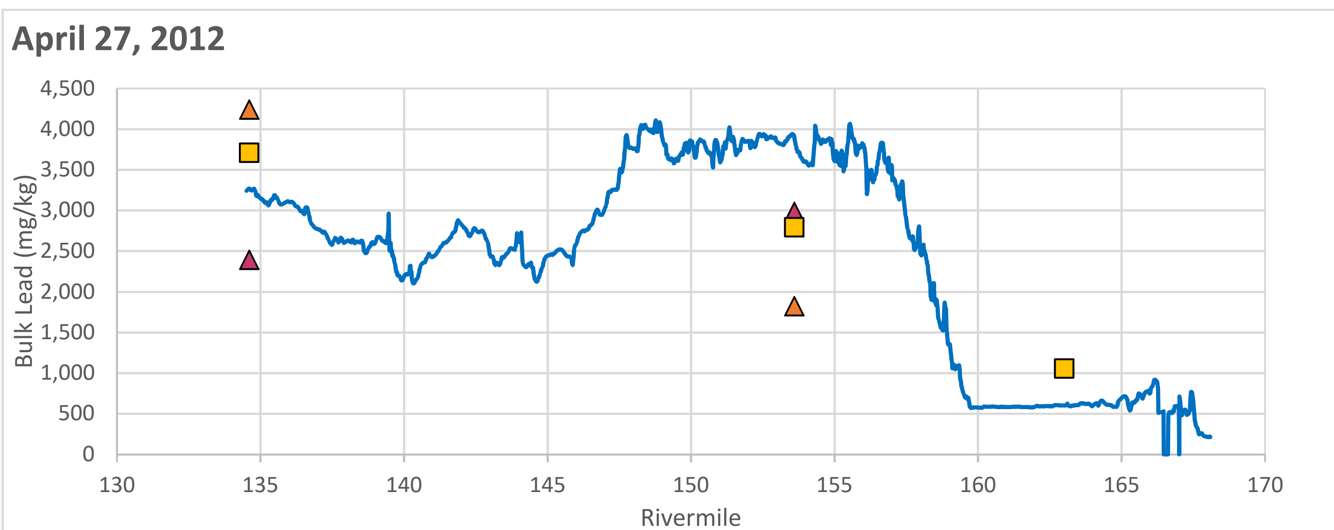
N

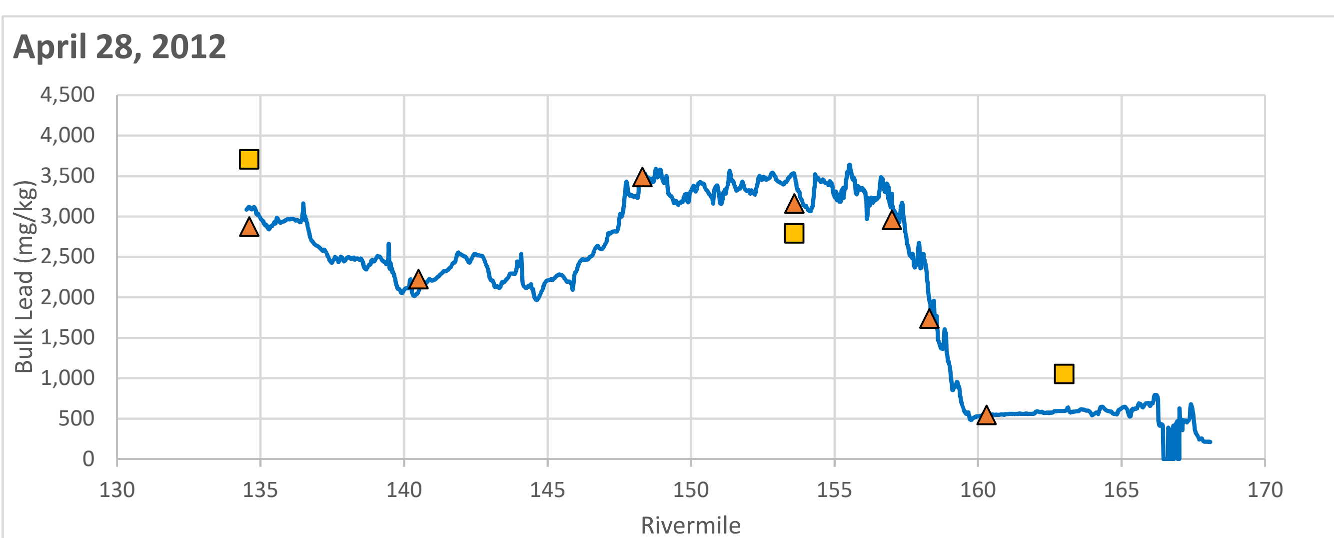
Exhibit 20. **Deposition Rate and Surface XRF Lead Concentrations**
Synopsis
Lower Basin Coeur d'Alene River (OU3)

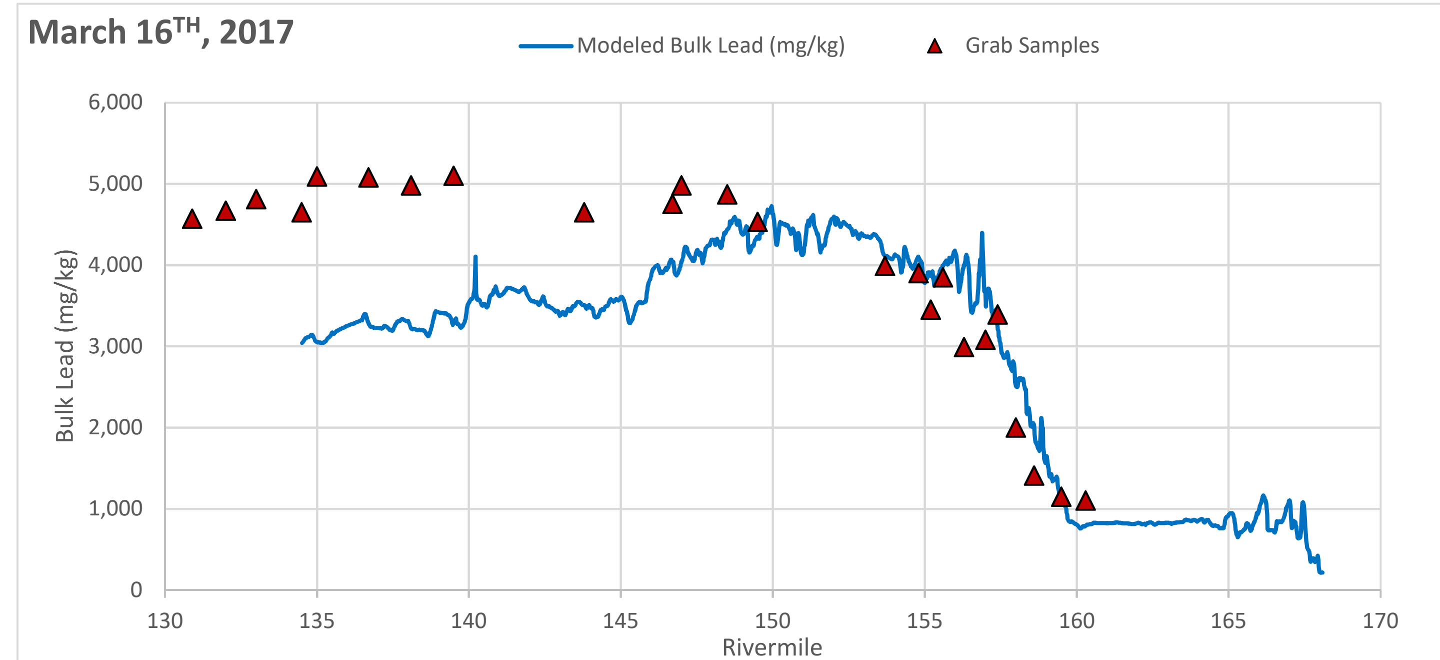
D:\CH2M-PROJECTS\676513CH_CDA\MAPFILES\FP_DEPOSITIONDEPTH.MXD TB028345 7/15/2019 9:07:40 PM

ch2m









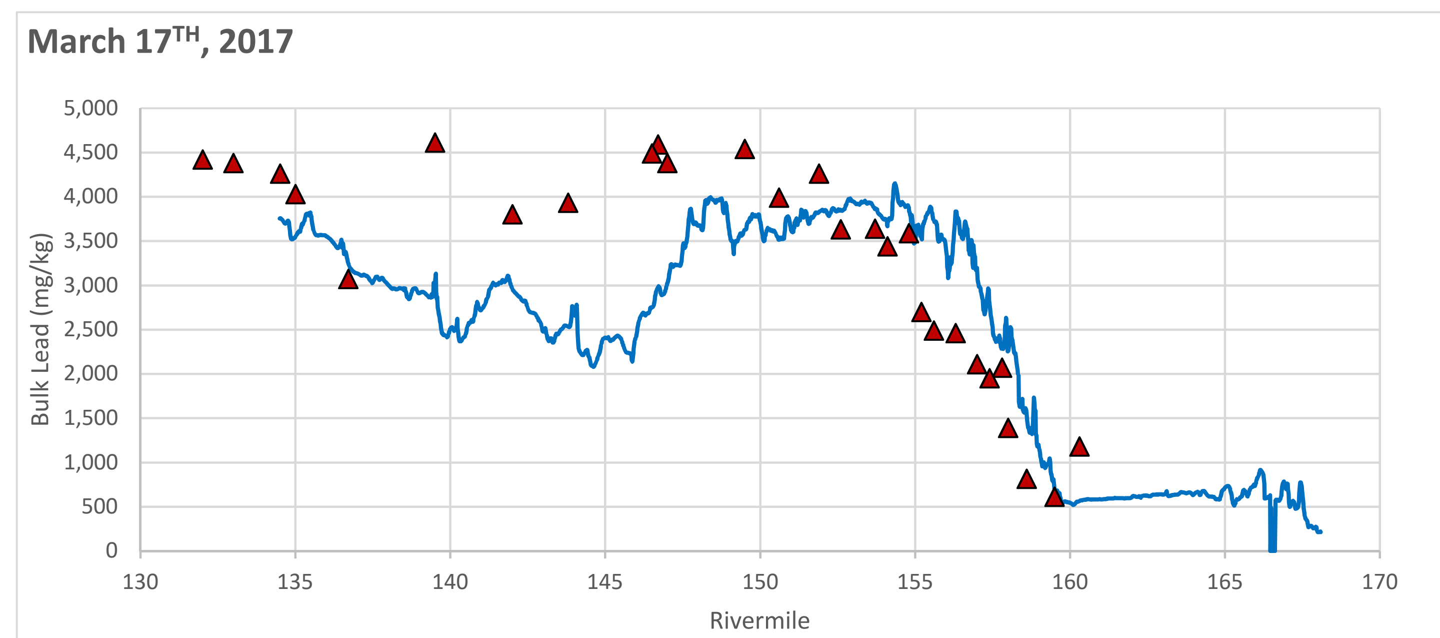


Exhibit 21. **Modeled and Observed Bulk Lead Concentrations for the 2012 and 2017 Flood Events**

Synopsis

Lower Basin Coeur d'Alene River (OU3)